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1863.

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VOLUME IV.

1863.

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ERRATA IN VOL. IV.

Page 8, heading of second column in the table, for "Total," *read* "Per square foot;" and in heading of third column in the table, for "Per square foot," *read* "Total."

Page 8, for the number of foot lbs. per square foot on the 8-inch shield, *read* "242,316;" and for the number on the 10-inch embrasure, *read* "492,933."

Page 100, line 19, for "Plate IV.," *read* "Plate III."

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OBJECTS OF THE INSTITUTION.

The objects of the Institution of Naval Architects—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads :—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made, then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. The Institution of Naval Architects shall consist of four classes, *viz.*, Members, Associates, Honorary Members, and Honorary Associates.

2. *Members.*—The Class of Members shall consist exclusively of Naval Architects.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified, either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons who are eligible as Members, and upon whom the Council may see fit to confer an honorary distinction.

5. *Honorary Associates.*—The Class of Honorary Associates shall consist of persons who have contributed to the improvement of ships or their equipment, and upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

6. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

7. A General Meeting of the Members and Associates of the Institution shall be held annually; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

8. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the Election of Associate Members of Council, the Treasurer and the Auditors.

9. As soon as may be convenient after the Annual General Meeting, the newly-elected Members and Associate Members of Council shall meet and elect the President and Vice-Presidents for the year, Members and Associate Members of Council both voting.

10. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all Meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

11. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

12. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present, to preside.

13. The Chairman at any Meeting of the Council or of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

14. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

15. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members last, be entitled to sit and vote with the Members of Council.

16. *Members of Council.*—Members only shall be eligible for Election as Members of Council at the Annual General Meeting.

17. *Associate Members of Council.*—Associates only shall be eligible for Election as Associate Members of Council at the Annual General Meeting.

18. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

19. The Council shall meet as often as the business of the Institution requires, and at every Meeting five "Members of Council" shall form a *quorum.*

20. The Council may appoint Committees to report to them upon special subjects.

21. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding Meeting of the Council.

22. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

23. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

24. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide

for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

25. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council, and are still Members of the Institution, shall be eligible for election as Treasurer.

26. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

27. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

28. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

29. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

DESIGNATION OF MEMBERS AND ASSOCIATES.

30. Any Member, Associate, Honorary Member, or Honorary Associate, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, *viz.:* M.I.N.A.; Assoc. I.N.A.; Hon. Mem. I.N.A.; Hon. Assoc. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

31. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulation:—

> He shall submit to the Council a statement, showing that he has been professionally engaged in shipbuilding for at least seven years in some public or private shipbuilding establishment, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, and to be admitted as such to the Membership of the Institution. This shall be signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement.

32. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, and such four-fifths constitute a majority of the professional Members of the Council, his proposal for admission shall be submitted to the Members of the Institution (who shall have access to the applicant's statement) at an Ordinary Meeting of the Institution, for them to vote upon, by ballot.

33. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if

approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon by ballot.

34. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

35. Each Member and Associate shall pay an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future Subscriptions on the 1st day of January.

36. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

MEETINGS.

37. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

38. The Transactions of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

39. The Transactions shall not be sold, or supplied for sale, by the Institution; but a copy shall be sent free to each Member and Associate.

INTRODUCTORY PROCEEDINGS.

THE Annual Meetings of the Institution for the reading and discussion of Papers took place at the Hall of the Society of Arts, John Street, Adelphi, on the 26th of March last, and were continued throughout the two following days.

The proceedings commenced by the reading of the Report of the Council, which was as follows:—

REPORT OF THE COUNCIL, I.N.A., MARCH, 1863.

"It will be unnecessary for the Council to address to the Members and Associates on the present occasion more than a very few words in the shape of a Report.

"During the past year a few Associates have, from various causes, chiefly private and personal, withdrawn from the Institution, but their places have been much more than supplied by the entrance of thirty-three new Associates, among whom are Capt. Phillimore, R.N., of H.M.S. *Defence;* Capt. Chamberlain, R.N., of H.M.S. *Resistance;* Admiral Sir James Hope, K.C.B., who has lately returned from a distinguished career in China; Admiral Paris, C.B., of the French Imperial Navy, an officer as distinguished for his scientific attainments as for his gallantry in action; and numerous other officers of the British and Foreign War Navies, together with several engineers and other civilians, whose names will, of course, appear in the next volume of *Transactions.* An Election of Members has also taken place, and several able naval architects have been added to our body.

"The Council have to congratulate the Institution on the kindness and readiness with which numerous gentlemen have prepared and contributed Papers to be read at these meetings. Many subjects of the greatest possible importance will, at the present time, engage your attention, and will doubtless be discussed with that calmness and moderation which should never be exceeded in scientific discussions. The Council have to acknowledge, with some regret, that the private shipbuilders of the country have not contributed Papers with that freedom which was anticipated. In many parts of the country vessels of a composite character, with frames of iron and planks of wood, are being constructed, and it is impossible for a naval architect to view these great and interesting experiments without interest, or without desiring to learn the details of construction adopted by the various builders, and the results which they have been found to yield. The Council earnestly hope that during the coming year this subject will be carefully borne in mind by the Members, and that next year the Institution will receive full accounts of the several plans now under trial.

"The Council also repeat, in the most emphatic and public manner, the invitation which they have all along held out to the Members and Associates, and would again urge them to communicate freely to the

Institution the results of their professional knowledge and experience, in the form of carefully-prepared Papers, to be read at these public gatherings of the body.

"The Council are glad to be able to state that the finances of the Institution are in as flourishing a condition as they were at the period of their last Report, as will apppear from the Financial Statement which will be appended to this Report in the *Transactions*. They also desire to acknowledge, with thanks, the receipt of several books, models, &c., from friends of the Institution.

"The retirement of the Secretary of the Institution, Mr. E. J. Reed, has been placed in the hands of the Council, who have accepted it; but Mr. Reed has offered to perform the duties of the Secretaryship throughout the present meetings, and to attend to the interests of the Institution until a successor is appointed, and the Council have availed themselves of that proposal."

After the reading of the above Report, it was put to the Meeting (there being no change in the Council proposed) that the officers, as they then stood upon the list should be re-elected, excepting only the Secretary, whose resignation had been tendered to, and accepted by the Council. This resolution was unanimously agreed to.

A Council Meeting was held at the Offices of the Institution, 7, Adelphi-terrace, on the 18th of April last, and at which the following officers were present:—Sir John Pakington, President (in the Chair); R. Abcthell, H. Chatfield, J. Laird, F. Lloyd, J. Penn, J. Scott Russell, I. Watts, Esqrs., and the Rev. Dr. Woolley, Vice-Presidents; J. Grantham, and C. H. Wigram, Esqrs., Members of Council; and Sir Edward Belcher, Admiral Halsted, and G. W. Lenox, and J. Mac Gregor, Esqrs., Associate Members of Council.

At this Meeting Mr. Grantham proposed, and Mr. Scott Russell seconded the following Resolution, which was carried unanimously:—

"That the Council having received from Mr. Reed his resignation of the office of Secretary, held by "him with so much advantage to the Institution since its commencement, take this occasion to express "their appreciation of his services in promoting this important work, and to record the prominent part he "has taken in bringing it to its present high position. And while regretting the step which Mr. Reed has "found it necessary to take, they desire to convey to him their best wishes for his future success in life, and "trust he may long adorn the profession of which he is a member.

"The Council further express a desire that Mr. Reed should allow himself to be nominated a Member "of the Council."

It was also resolved:—

"That the above Resolution be entered on the proceedings of the Institution."

It was next moved by Mr. Grantham, and seconded by Admiral Halsted:—

"That an Executive Committee consisting of Dr. Woolley and Mr. Scott Russell be appointed to "conduct the affairs of the Institution through the ensuing year; to take preliminary steps for supplying "the vacant Secretaryship; and to provide in the meantime for the performance of the Secretary's duties:

"And for this purpose that the necessary funds be placed at their disposal by the Council." This Resolution was carried unanimously.

The President next proposed, and it was resolved unanimously :—

" That a Sub-Committee of this Council be appointed to draw out a scheme for the consideration of " the Council, with a view to the formation of a School of Naval Architecture, this said Sub-Committee " consisting of—

" The Rev. Dr. Woolley.
" The Rev. Canon Moseley.
" Mr. Watts.
" Mr. Scott Russell.
" Mr. Ritchie.
" Mr. Penn.
" Admiral Halsted."

It is with much regret that we have to announce the decease of Mr. Samuel Read, Honorary Member and late Member of Council; also of Lord Templetown, Admiral Leigh, Captains W. F. Burnett, C.B., of H.M.S. *Orpheus*, and J. N. Gladstone, M.P., and Messrs. D. Nutt, J. Sherriffs, and J. Wells, Associates. Through the kindness of Mr. Joseph Large we have been favoured with the following short memoir of Mr. Samuel Read:—

Mr. Samuel Read entered the service in 1813, as a student of naval architecture in the Royal Naval College at Portsmouth, and having passed with the greatest credit through the prescribed course of studies in the theory and practice of his profession, he at once entered on the executive duties connected therewith in the dockyards, and in 1847 became master shipwright at Sheerness. Previously to receiving this appointment he had been selected to be a member of several very important Committees appointed by the Admiralty for the improvement of naval architecture. The first was established by the Earl of Haddington, in the year 1842, with the object of furnishing a series of designs for ships of war, to be accompanied by an explicit statement of the method pursued in preparing them. This task he, in conjunction with the other members, Mr. Chatfield and Mr. Creuze, accomplished in a manner which must have given the highest satisfaction.

The large volume containing the results of these labours, and which the Admiralty subsequently ordered to be printed, consists of three valuable reports on the subject of naval architecture, and a great number of tables of useful practical data. The ships built from the designs of the Committee were highly approved of for their sea-going qualities. The next Committee on which Mr. Read served was the " Committee of Reference," appointed by Lord Auckland, in 1846, of which Lord John Hay, at that time a Lord of the Admiralty, was President. This Committee was instituted for the purpose of reporting on the designs of ships referred to it by the Admiralty.

The last Committee of which Mr. Read was a Member was the " Council of Science," appointed in 1848, he being at that time master shipwright at Sheerness. The functions of this Committee were of the same character as those of the " Committee of Reference." While engaged in his multifarious official duties, Mr. Read still ardently pursued the study of the Theory of Naval Architecture. The published Papers written by him display an amount of ability and knowledge which placed them among the best works on this difficult subject. Although Mr. Read greatly assisted in the establishment of the Institution of Naval Architects, and by the valuable Papers which he subsequently contributed added to its usefulness, there can be no doubt, from the great interest he took in the Institution, that if the state of his health had

permitted, far greater assistance would have been rendered by him. As a proof of his earnest desire to further the objects of this Institution may be mentioned the gift by him of nearly 50 books, many of which are of the greatest value to the Naval Architect. This gift was gratefully acknowledged in the Second Volume of our *Transactions*, a list of the most important works being appended. For the last few years Mr. Read's health had unfortunately been declining, and he was unable to take any part in the introduction of those great changes consequent on the application of iron armour plates to men-of-war; but so fully sensible were the Council of his professional eminence, and of the merit of his services, that they conferred upon him last year the only distinction in their power—the Honorary Membership of this Institution. Mr. Read was kind, warm hearted, and generous in his disposition, of unbending integrity, and an unflinching advocate of whatever he considered to be right. No man ever possessed the affection and confidence of his intimate friends, and the esteem of all who were associated with him, in a greater degree than he did, and his death cannot but be regarded as a great loss, not only to his immediate friends but to the Shipbuilding profession in general.

INSTITUTION OF NAVAL ARCHITECTS *in account with* J. D'AGUILAR SAMUDA, ESQ., *Treasurer*.

Dr.

1862.		£	*s.*	*d.*
Aug. 4.	To Balance in hand of Treasurer ...	220	19	7
Oct. 25.	„ Subscriptions from Capt. Haro ...	4	4	0
Nov. 12.	„ Ditto „ the Secretary .	200	0	0
1863.				
Jan. 10.	„ Ditto „ „ „	70	0	0
Feb. 10.	„ Ditto „ „ „	241	10	0
„ 26.	„ Ditto „ „ „	130	0	0
Mar. 21.	„ Ditto „ „ „	220	0	0
„ 23.	„ Ditto „ „ „	26	1	3
		£1,112	14	10

Cr.

1862.		£	*s.*	*d.*
Dec. 23.	By Reporter's Account	22	11	6
1863.				
Jan. 10.	„ Rent (2 quarters)	50	4	0
Feb. 10.	„ Secretary's Salary (3 quarters) ...	225	0	0
„	„ Discount on Country Cheques ...	0	1	1
Mar. 23.	„ Balance	814	18	3
		£1,112	14	10

1863.
Mar. 23. To Balance..... .... 814 18 3

(Signed) J. D'A. SAMUDA, *Treasurer*.
P. THORNTON, J. LUKE, } *Auditors*.
E. J. REED, *Secretary*.

PAPERS AND DISCUSSIONS.

ON THE CONSTRUCTION OF IRON-PLATED SHIPS.*

By W. Fairbairn, Esq., LL.D., F.R.S., Hon. Assoc. I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 26th, 1863; the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

The future destiny of nations seems to be involved in the consideration of iron, and its application to an entirely new system of construction in vessels of war, calculated to unite with equal facility the powers of attack and defence. To combine this force and power of resistance in one construction, is a desideratum not yet attained, but every effort is now being made by the Government of this and other maritime nations, to approximate as nearly as possible in the construction of ships of war to that desirable object. It appears from what has already been done by the Government of this country, and the preparations now going forward in the French dockyards, as also from the trials and experiments made in America, that the war ships and fleets of the future will undergo a thorough change, not only in form, but also in the material used in their construction. Thirty years' experience in the appliance of iron to the building of our mercantile navy, has shown the great superiority of that material for shipbuilding; and much greater progress in this direction would have been made in the Government dockyards, but for two reasons, namely, the strong prejudices engendered against iron in the first instance, and the dangers arising from the effects of shot on iron ships in the second.

As early as 1834-5, the Admiralty were urged to institute a series of experiments, to solve the difficulties which appeared to surround these opinions; but it required several years before their Lordships made up their minds as to what should be done. At last, through the influence of the late Admiral Sir George Cockburn, and others, the subject of iron ships was brought under consideration, and targets were ordered to be prepared at Woolwich, for experiment with a 32-pounder smooth-bore gun, at a range of only thirty yards. The result was condemnatory of the use of iron, and the Admiralty then fell back upon the old wooden walls, as the only class of vessels calculated for the purposes of war. This decision on the part of the Government

* Received March 26th, 1863.

retarded everything in the shape of progress, until the French Emperor, in 1855, gave a fresh impetus to the subject, by the introduction of thick iron plates for casing the sides of vessels, as a medium of resistance to projectiles at high velocities. This innovation—or invasion as it is now called—upon old constructions roused the lethargy into which we had fallen, and shewed the weakness of our fleets and squadrons, when exposed to the attacks of "iron-clads" of superior force, thoroughly protected by defensive armour. These facts, so strikingly exemplified by the French iron-cased batteries during the Crimean war, could no longer be resisted, and hence followed the changes and experiments which are now in progress. It would be premature to conjecture what may be the ultimate results of those changes, as fortunately we are not engaged in war to enable us practically to test the efficiency of the vessels already built on the new principle; nor have we sufficient experience to enable the Admiralty to determine what size, form, and class of vessels are best adapted for a particular service. We are, however, feeling our way by experiment in the right direction, and we may safely predict a new and successful era in the construction of iron vessels, calculated to meet all the requirements of a powerful and effective navy.

Whatever may be the issue of the present movements, the Board of Admiralty are entitled to every commendation for the liberal and effective manner in which they are endeavouring to meet the changes now pending over the destiny of the country. They do not appear to be guided by precedents or the influence of bygone times, but are open to the opinions of sound practical men, and those, supported by experimental facts, are the true harbingers of success. Whatever may have been the shortcomings of past administrations, it must be admitted that the present Board of Admiralty are actuated by a sincere desire for the improvement of the navy and the advancement of the public service; and, considering the heavy responsibilities involved in the transfer of the whole British Navy from wood to iron, exclusive of the additional circumstance of having them fire-proof and shot-proof, it is not too much to say that the noblemen and gentlemen of that department have gone the right way to work to meet the requirements of an entirely new construction, and to render the future navy of England equally effective under every condition of power and speed for the double purpose of attack and defence.

Viewing the subject in this light, and giving the Government credit for the desire to go cautiously and safely to work, it may be determined in the first instance to ascertain by experiment the following important facts:—

1. The power and description of ordnance that vessels may be called upon to resist:
2. What description of iron plating, what quality of metal, and what thickness and form of plates are requisite to resist the entrance of shot and shell from the most powerful guns:

3. The form of vessels, tonnage, displacement, and power necessary to propel them at a given speed; and
4. The mode of fastening the armour plates, the nature of the backing, and other conditions essential to the development of a shot-proof iron ship.

Now all these important conditions have been enquired into, and to some extent ascertained by direct experiment; and formulæ have been deduced from the experiments to shew the power as far as is at present known of the enemy's guns; the sort of iron required to resist them; and the size, form, and description of vessels best adapted to meet these requirements.

It may be interesting to notice briefly these results in the order in which they are given above, and to exhibit the great attention which has been bestowed on a subject of such vast national importance. Viewing them in this light, we will consider, first, *the power and description of ordnance by which vessels of war may be assailed.*

It is generally known that a new kind of rifle first introduced by M. Minié into the French service gave results superior to similar constructions in this country, and that it directed the attention, not only of the Horse Guards and the War Office, but also of the public at large to the achievements, long range, and precision of fire which it attained over the common rifle. Now in guns, in ships, and in munitions of war, this country cannot afford to be behind any other nation, whatever may be its power or means for aggression; and the result of this invention introduced through the War Office a series of experiments by Mr. Whitworth to meet the improvements introduced by M. Minié.

Mr. Whitworth after much thought and labour produced a rifle much more accurate and more powerful than the Minié; and his experiments were extended to breach-loading guns of large calibre on the same principle of hexagonal shot as his small rifle. During these experiments Mr., now Sir W., Armstrong introduced his rifled gun, which met the requirements of the War Office; and from that time to the present Sir William has been the ordnance constructor to the Admiralty as well as to the War Office.

For several years the Armstrong guns (chiefly breach-loaders) have done good service. All of them from 6 to 300-pounders have been employed in conjunction with the 68-pounder smooth-bore in the experiments at Shoeburyness; and it is interesting to observe, that the 120-pounder shunt gun, with a charge of 27lbs. of powder, was nearly equal to the resistance of a $4\frac{1}{2}$-inch plate at a distance of 200 yards. The same gun with an equal charge was, however, unable to make much impression on the same plate when supported by a solid backing of wood, similar to the sides of the *Warrior*. The 300-pounder Armstrong smooth-bore gun with a 150lb. bolt and a charge of 50lbs. of powder, however, penetrated the *Warrior* target, with its $4\frac{1}{2}$-inch plates and 18 inches of solid teak backing.

Matters were in this state when Mr. Whitworth was permitted to try his 40, 70, and 120-pounder rifled guns against similarly constructed targets; and the results of those experiments overturned all previous impressions as to the power of projectiles when delivered at a distance of 200 yards. It is true that Mr. Whitworth's shot and shell were made of hardened steel or homogeneous iron, but the results were greatly superior to those of any previous experiments. The following table gives an abstract of the results:—

Experiments with the Whitworth Guns on 4½ and 2½-inch Targets.

No. of rounds.	Description of Ordnance.	PROJECTILES.			Charge of powder in lbs.	Range in yards.	Indent in inches.	Velocity at 580 yards.	Thickness of plate.
		Nature.	Form.	Weight.					
1	120-pounder muzzle loading rifled gun	Shell—homogeneous metal	Cylindrical—flat-ended	151	27	800	through	1,170	4½ in.
2	,,	,,	,,	,,	,,	,,	,,	1,880	,,
3	,,	Hollow cast iron	,,	130	,,	,,	2·3	1,277	,,
4	,,	Solid shot—homogeneous metal	,,	129·5	,,	,,	through	1,204	,,
5	70-pounder	Shell—homogeneous metal	Flat-ended	81	13	600	,,	1,107	,,
6	,,	,,	,,	69	,,	,,	1·55	1,146	,,
7	12-pounder breech loading rifled gun	Solid shot—cast iron	,,	12	1¾	200	·85	—	2½ in.
8	,,	Shell	,,	12·2	1¾	,,	through	—	,,
9	,,	Homogeneous metal	,,	12·1	1¾	,,	,,	—	,,

On a former occasion I endeavoured to establish the formula which led me to insist on the waste of work by cast iron shot in consequence of their own disruption. These results did not at first appear sufficiently reliable, based as they were on experiments with a single piece of ordnance of extremely small calibre. We have now, however, the results of the trials with the Whitworth guns, as given in the table, with steel projectiles flattened like those of the wall-piece; and it therefore appears desirable to examine how far the anticipation of a high penetrative power in such missiles is borne out by facts.

Unfortunately the experiments with the Whitworth gun are not complete enough to determine the *maximum* thickness of perforation. In every case the armour plate was pierced by the steel shot, and we are not entitled to infer that a somewhat greater thickness would not also have been perforated. This might have been the case or it might not, but until the point at which the shot is thrown back from the target without perforating is ascertained, we are not at liberty to assume that the *maximum* thickness of perforation has been reached; and hence we are without the necessary data for deducing a constant.

I have, nevertheless, calculated for the sake of comparison, the *maximum* thickness of perforation for the Whitworth projectiles, by means of the formula deduced from the experiments with the wall-piece, and in the following table these results are placed side by side with the thicknesses actually perforated in the Shoeburyness experiments:—

Comparison of Formulæ deduced from Results with Wall-Piece, and Experiments with Whitworth's Steel Projectiles.

Description of Gun.	Weight of shot in lbs.	Charge of powder in lbs.	Velocity of shot in feet per second.	Semi-diameter of shot in inches.	Maximum thickness of penetration by formula in inches.	Thickness actually penetrated in inches.
Wall-piece	0·3438	—	1,141	0·435	0·81	0·81
Whitworth..... 12-pr.	12·06	1·875	1,202 *a*	1·500	2·72	2·50
,, ... 12-pr.	12·16	1·750	1,157 *a*	1·500	2·63	2·00 *b*
,, ... 70-pr.	68·50	12·000	1,276	2·750	5·09	4·00 *c*
,, ... 120-pr.	129·00	23·000	1,278	3·500	6·20	4·50 *d*
,, ... 120-pr.	130·00	25·000	1,268	3·500	6·17	4·50 *e*
March 17th, new experiment } 120-pr.	130·00	25·000	—	3·500	6·17	5·50

a These velocities are calculated.

b The shell penetrated 12 inches of wood backing, and buried itself in a sandbank behind.

c This shot penetrated 13 inches of wood backing, and indented and cracked a 2-inch plate in the rear.

d This shot penetrated 20 inches of wood backing, and fractured the iron skin.

e The shell burst whilst penetrating the wood backing.

The results here given are satisfactory, considering the limited number of experiments which have been made; and it will probably be found that the resistance to projectiles is not exactly as the square of the thickness, but in a slightly less ratio.

Still further to illustrate the composition and force of shot calculated to pierce iron plates, a long series of experiments was instituted for the purpose of ascertaining by actual pressure the force required to break up shot composed of cast iron, wrought iron, and steel, and to compare them on impact. It is instructive as well as interesting to ascertain, not only the form, but also the material of which shot is composed to produce certain effects; for example, as regards form it requires double the force to crush cylindrical shot with flat ends as compared with those of round ends. This will be seen from the following experimental results on statical pressure:—

Shots with	cast iron flat ends crushed with	55·32	tons per sq. inch.
,, ,,	Cast iron round ends crushed with	26·86	,,
,, ,,	Wrought iron flat ends distorted by compression	74·00	,,
,, ,,	Wrought iron round ends ,,	49·89	,,
,, ,,	Steel flat ends slightly compressed, but not crushed	120·27	,,
,, ,,	Steel round ends crushed with	90·46	,,

From the foregoing we may conclude that the steel shot with flat ends would have followed the same law as the cast iron, provided the apparatus had been sufficiently strong to crush the specimen, which was not the case.

It has been correctly stated that it requires a considerable amount of force to break up shot when delivered with great velocity against an unyielding object, such as the side of an iron-cased ship or a target representing a portion of such a structure, and hence it may be concluded that the force expended in thus breaking up the shot must be deducted from that employed in doing work upon the plate. This is confirmed by experiment, which shews, that although the whole of the force contained in the ball, when discharged from a gun at a given velocity, must be delivered upon the target, yet, the amount of work, or damage done to the plate, will depend upon the weight and tenacity of the material of which the shot is composed. If, for example, we take two balls of the same weight, one of cast iron and the other of wrought iron, and deliver each of them upon the target with the same velocity it is obvious that both balls carry with them the same projectile force as if they were composed of identically the same material. The dynamic effect, or work done, is, however, widely different in the two cases, the one being brittle and the other tough: the result is that the cast iron is broken to pieces by the concussion of the blow, whilst the other either penetrates the plate, or, what is more probable, flattens its surface into a greatly increased area, and inflicts a greater amount of punishment upon it. In this instance, the amount of work done is in favour of the wrought iron shot. It does not, however, alter the condition in which the force was, in the first instance, delivered upon the target, but is entirely due to the superior tenacity of the wrought iron shot to that of the cast iron, which yields to the blow, and is broken in pieces in consequence of its inferior powers of resistance. The same may be said of steel in a much higher degree, and this was forcibly exemplified in the experiments with the Whitworth shot and shell. In this case it will be observed that the shot inflicted nearly the whole of its *vis viva* upon the target by perforating the plate. It was the same with the shell which exploded after it had gone through the plate; and from this it is obvious that the work done, or the whole dynamic effect, was not expended in perforating the plate alone, but that a certain portion was held in reserve to penetrate the backing and indent the skin on the back of the target.

Having described the force and nature of the ordnance and projectiles by which our ships and forts may be penetrated and attacked, we have next to consider what description of shield is best calculated to resist such powerful artillery, and the requisite quality of the material to be employed for that purpose.

A long series of experiments, conducted with great care, has determined that the

material which presents the greatest power of resistance to projectiles at high velocities is the softest and best description of *well-wrought* malleable iron. I use the term "well-"wrought" for the purpose of showing that it is necessary to pass the mass from which the armour plates are manufactured through the different processes of hammering, welding, and rolling, in order to give it the required fibre, toughness, and ductility to resist impact. For many purposes these repeated processes of manipulation are not necessary; but if we are to have a description of material of *maximum* resistance, it can only be obtained from the best quality of iron, carefully prepared by a system of operations calculated to increase its tenacity.

We have shewn in the foregoing table the thickness of plates perforated by the Whitworth homogeneous shot and shell, and in order still further to develope the relation which exists between the forces of impact, as derived from projectiles and that of statical pressure, it may be interesting to know that in the latter case the resistance of plates varies directly as the thickness; that is, if the thickness be as the numbers 1, 2, 3, &c., the resistance will be as 1, 2, 3, &c.; but those obtained by impact shew that up to a certain thickness the resistance to projectiles increases nearly as the square of the thickness; or, in other words, if the thickness be 1, 2, 3, 4, &c., as before, the resistance to impact will be as the numbers 1, 4, 9, 16, &c., respectively. The measure of the destructive power of shot is, therefore, its *vis viva*, and not its momentum as has been sometimes supposed; but the work accumulated in it varies directly as the weight of the shot, multiplied into the square of the velocity.

There is, therefore, a great difference between statical pressure and dynamical effect; and in order to ascertain the difference between flat-ended and round-ended shot, a series of experiments was undertaken with an instrument or punch exactly similar in size and diameter, and precisely corresponding with the steel shot of the wall-piece, (·85 inches diameter), employed in the experiments at Shoeburyness. The result on the plates marked A, B, C, D, were as follows:—

Character of Plates.		Resistance in lbs.	
		Punch, flat-ended.	Punch, round-ended.
½-inch thick	A Plates	57,956	61,886
	B Plates	57,060	48,788
	C Plates	71,035	85,524
	D Plates	49,080	43,337
¾-inch thick	B Plates	84,587	98,420
	D Plates	82,381	98,571
Mean		67,017	72,754

These figures show, that the statical resistance to punching is about the same, whether the punch be flat-ended or round-ended, the mean being in the ratio of 1,000 : 1,085, or $8\frac{1}{2}$ per cent. greater in the round-ended punch. It is, however, widely different when we consider the depth of indentation of the flat-ended punch, and compare it with that produced by the round-ended one, which is $3\frac{1}{2}$ times greater. Hence we derive this remarkable deduction, that whilst the statical resistance of plates to punching is nearly the same, whatever may be the form of the punch, yet the dynamic resistance or work done in punching is twice as great with a round-ended punch as with a flat-ended one. This, of course, only approximately expresses the true law; but it exhibits a remarkable coincidence with the results obtained by ordnance at Shoeburyness, and explains the difference which has been observed in these experiments, more particularly in those instances where round shot was discharged from smooth-bore guns at high velocities. To ascertain more clearly the dynamic effect, or work done by the weight of shot which struck some of the targets at different velocities, let us examine the following results:—

Target.	Weight of Shot striking target. lbs.	Work done on Target.	
		Total Foot lbs.	Per square foot. Foot lbs.
8-inch Shield.....	1,253	—	29,078,000
10-inch Embrasure	1,511	—	37,140,000
Robert's Target	946	822,000	19,726,000
Fairbairn's Target.....	1,024	324,000	23,311,000
Warrior Target	3,229	312,000	62,570,000
The Committee's Target ...	6,410	—	124,098,780

From the above, it will be observed that the last two targets have sustained in work done what would, if concentrated, be sufficient to sink the largest vessel in the British Navy. Still further to illustrate the effect of shot upon iron targets, or the sides of an iron-cased vessel, we may state that the shot of a gun is simply the means of transferring mechanical power from one place to another. The gunpowder in the gun developes by its combustion a certain quantity of mechanical force, or work as it is now called, and the object of the shot is to convey this work to a distance, and apply it to an object supposed to be otherwise inaccessible. The effect of this, according to Mr. Pole's formula, is,—

W = weight of shot in lbs.
V = its velocity in feet per second.

Then by the principle of *vis viva*, the quantity of work stored up by the moving mass, measured in lbs. one foot high, is $= \frac{WV^2}{2g}$, g being the force of gravity $= 32\frac{1}{6}$.

Thus, if we take a shot like that recently used against the *Warrior* target, 156 lbs., moving at the rate of 1,700 feet per second, the work done will be

$$\frac{156 \times (1{,}700)^2}{64\frac{1}{3}} = 7{,}008{,}238 \text{ lbs. one foot high;}$$

shewing at once the immense power that this small body is able to deliver on every resisting medium tending to arrest its course and bring it to a state of rest. Or, in other words, it is equivalent to raising upwards of 3,000 tons a foot high in the air.

Having ascertained the thickness of plates which ordnance of certain calibre is able to perforate, it now becomes a question of great importance to know to what extent the improvement in gunnery may yet be carried, and what thickness of plated armour will be required to resist the force of a concentrated battery of the largest guns that can be made. Sir W. Armstrong has already constructed a 300-pounder which has, with a charge of 50 lbs. of powder and a 150-lb. bolt, made its way completely through the *Warrior* target; and, I believe, both that gentleman and Mr. Whitworth are prepared to construct guns of double that force, provided it can be accomplished without the risk of bursting; in fact, it has been intimated that whatever description or thickness of iron is used in the shape of armour they will make guns to penetrate it. If this be true, the guns must eventually become the victors. Acting however on the defensive we are not prepared to admit these views, as there appear to be limits to the strength of guns, as well as the strength of plates, and I am not quite sure that the 300-pounder has not attained its maximum strength. Assuming it is possible to make 600-pounder guns, and that such can be worked on board ship, we have yet to discuss under what form they can be made secure or rendered formidable under conditions of which we have no knowledge, and to which science and practical experience have not been applied. In the sequel we hope to be able to discuss this question more in detail; for the present we shall confine our investigations to the 300-pounder, assuming that guns of that power are more manageable and better adapted to the service of the navy than ordnance of a much larger calibre. Taking therefore the 300-pounder guns as the *maximum* force that ships of war can use, we require to ascertain what description of vessel and strength of armour plates are necessary to resist a battery of such immense force, and how the ship is to carry so great an increase of weight. It has been calculated that our largest vessels, such as the *Warrior* and *Black Prince*, could not carry with safety plates thicker than 5 inches; and with this load, and all her stores, armament, &c. on board, it is very questionable, notwithstanding her speed and great power of engines, whether or not she would be sufficiently lively at sea. I am inclined to think she would be quite the reverse, supposing she had 1,300 tons of plates on her sides, including her machinery and all the other requisites for a vessel of her class. Viewing the subject in

this light, and taking into consideration the weight of plates that a ship can carry without destroying her efficiency as a sea-going vessel, it follows that certain sacrifices must be made as regards security, by the exposure of parts of the ship to the passage of the enemy's shot. To meet these requirements and save the ship from absolute destruction it would be necessary to construct the battery at midships on the *Warrior* and Mr. Reed's principle. In this construction 6, 7, or 8-inch plates might be used without danger to the strength or sea-going properties of the ship.

We have seen by experiment that a $4\frac{1}{2}$-inch plate on the side of a ship, with solid teak backing, is capable of resisting either cast or wrought iron shot from a 120-pounder gun; and by the formula,* a plate 5·2 inches thick would resist a 300-pounder spherical cast iron shot. Now, as plates of that thickness would be much too heavy for a vessel larger than the *Warrior*, it follows that a new arrangement and distribution of the armour plates would be required. To accomplish this, the following considerations present themselves:—To attain celerity of motion, and the required power of resistance to the varied strains to which an ocean steamer is subjected, we must study with care and consideration in the first instance, the nature and properties of the material employed in the construction; and, in the second, the laws of distribution, by which every portion of the structure shall be equal in its powers of resistance to the work it has to perform.

In every description of constructive art this appears to be a most desirable object to accomplish, and in shipbuilding especially, it is a principle which ought to be carefully studied and judiciously applied. There are many constructions both of ships and bridges of great strength and great powers of resistance; but if examined with reference to their scientific proportions, many of them would be found of double the strength at one point, and essentially weak at another. Now, this great irregularity of strength is obtained by a useless waste of material, and in many cases, such as those of ships and bridges, it is not only useless but highly detrimental to the strength of the structure to give it more work to perform and more weight to carry than it is entitled to bear. The great desideratum in iron shipbuilding is, therefore, to consider how we are to arrive at the *maximum* of strength with the *minimum* of material; and for the attainment of this object I have ventured—in the absence of experiment—to point out certain conditions and certain laws which enter into the application of iron in the reconstruction of the navy.

On a former occasion I endeavoured to show the forms and appliances necessary to be observed in building an iron ship, and pointed out what I considered the weak points of our present constructions; whilst at the same time I urged the necessity of adhering

* The dynamic resistance of plates to impact is as the 1·74 power of the thickness.

strictly to the laws of proportion in giving uniformity of strength to every part of the structure. From these laws, founded on my own experimental researches, I have never deviated, and I am more and more convinced that their observance is essentially necessary at this important juncture of the transition of the navy of this great country from wood to iron.

Impressed with these views, and having no reliable results of experiments on ships, excepting those of an approximate character, to guide me, I can only suggest that all vessels whether for war or commerce, should be treated as regards their ultimate strength as hollow beams and girders: that all large ships should be of the cellular construction along the upper deck and along the hull to the keel, and double plated; and that the frames and plates should be of sufficient strength to support a covering of armour plates capable of resisting the heaviest ordnance.

Now, with respect to the first condition of strength, I must refer you to my Paper, "On the Strength of Iron Ships," published in the first volume of the *Transactions* of this Institution; and, as regards the second, I think the cellular system imperative, from the fact that it gives the required strength with the least expenditure of material, and it increases the security of the ship when double plated. The section shown in Fig. 1, Plate I, will best explain the form of construction which I deem necessary for such a purpose.

It will be observed that I consider armour-plated vessels as having only one fighting deck, as at A, and that they are plated from the top of the upper deck *a a*, down to *b b*, a sufficient depth below the water line. From this point downwards and all around, the hull should be of the cellular construction as shewn at *c c*, &c. Above those parts, from *b b* to the upper deck, I would have a covering of armour plates, either for the whole or part of the length of the ship, as may be deemed expedient, in order to meet the requirements of her tonnage, displacement, and powers of floatage.

In this construction I would also suggest that the vessel be strengthened along the whole line of the upper deck by six longitudinal cells under the iron deck beams, as shewn at *d d d* and *e e e*, Fig. 1, one of the cells on each side being of thick plates, triangular, and forming a continuous stringer bracket for strengthening the sides of the ship, and prepared for receiving the ends of the deck beams. In this arrangement it will be observed that the whole of the upper deck will be in combination with the cells and the sides of the ship, and this added to a covering of iron plates rivetted to the deck beams will give a power of resistance to strain corresponding with the cellular system below. It is now well known that the cellular form is the only one calculated to attain the *maximum* powers of resistance, with a flexible material such as wrought iron

plates, to a compressive strain. Nature works in this direction in all her constructions, and it has been demonstrated from direct experiment that nearly one-half the material is saved by the cellular system; or, in other words, it would require double the weight of metal on the deck of a ship, or the top of a girder, to resist a corresponding force of compression to that of tension.

Looking to the principle of uniting the upper deck beams with the longitudinal stringers, it would be necessary to have them flanged on both sides, and rivetted to the top plate and angle iron of the cells, as shewn at B, Fig. 2, A being the longitudinal cellular stringer, B the deck beam, C the deck plate, and D the wooden deck. Under the longitudinal cells marked *d′* and *e′* would be iron columns at convenient distances for the support of the decks, as shewn at E.

Fig. 3, represents a section of the longitudinal cell, the deck beam, covering plates, &c., of the upper deck. The whole is combined so as to offer an effectual and powerful resistance to the varied strains of pitching and rolling, and from this we may reasonably conclude that such a vessel is able to contend with the elements at sea, independently of her iron sides, and her power of resisting the enemy's shot.

Having pointed out the more prominent features of construction of an iron-clad ship, I would next venture to direct attention to the carrying powers of the vessel, and to what extent her armour plating can be carried without injury to her efficiency as a sea-going steamer.

It has been stated that the *Warrior* carries as great a weight of armour plates as she can bear, and that if loaded to any greater extent she would roll fearfully, and become unmanageable at sea. With her present load (if I am correctly informed) she is wet, plunges, and does not rise to the sea in a head wind, and moreover, requires a storm-deck over the forecastle to prevent her decks being flooded. Now, these are considerations which require to be taken into account in the construction of vessels of war, it being, in my opinion, desirable in the first instance to obtain an active, lively ship, with impregnable armour and *great speed*. All these qualities, independent of strength, are what appear to be wanting in ships of war; and to arrive or rather to approximate—as some sacrifices must be made—to these conditions, we shall require to adhere as closely to every minutia as the nature of the construction and circumstances will admit.

It may be true, as suggested, that in order to carry a sufficient weight and thickness of armour plates our ships must be made longer, and greatly increased in dimensions. In fact, some have gone so far as to recommend vessels as large as the *Great Eastern*, but I must confess I am not of that opinion, as vessels of that magnitude appear to be very unmanageable, and they could not possibly manœuvre with the same celerity as vessels

of one-third or one-fourth the tonnage. Again, I am persuaded, that too much may be sacrificed to armour plates at the expense of speed and other qualities equally essential to the security of a well-constructed and well-armed ship. I believe that officers of the navy are not favourable to very large and heavy-moving ships. They prefer compact, lively vessels, with good speed, to a large ship incapable of quick manœuvring, however fast she may steam ahead.

Assuming there is some truth in these remarks, it will be necessary to consider by what means the difficulties of weight, &c., are to be overcome, and what description of vessels is best suited for the public service. To the consideration of this question, both science and skill must be brought to bear, in order that iron-clad vessels may be so constructed as to contain all the elements of speed, security, and other conditions required for attack and defence. Taking, for example, a vessel of the same tonnage as the *Warrior* or the *Black Prince*, with an armament of heavy guns capable of perforating plates $6\frac{1}{2}$-inches thick, and supposing that it was necessary to cover the sides of such a vessel with plates from 7 to 8 inches thick, it is evident that this weight of armour would destroy her efficiency as a sea-going vessel. If this be the case, there is no alternative but to reduce the weight and concentrate the battery of heavy guns at midships. For this purpose the armour plates 7 or 8 inches thick, would only extend one-half or two-thirds the length of the ship, and the stem and stern would be left entirely free for the shot to pass through the fore and aft parts of the gun deck. On this plan, the length of the battery may be extended or contracted to suit the carrying powers of the ship. In vessels of this kind there can be no objection to the armour plates being discontinued both fore and aft beyond the iron-clad battery at midships, as the men working the guns would, on an emergency, be no more exposed than they were in former days on board of wooden vessels. The upper deck on this construction would require to be made strong in order to support two platform guns at the bow and stern, under circumstances where they may be required. On the other hand, it may be necessary to have iron-clad bulkheads at each end of the battery, to prevent the vessel being raked by an enemy's shot. With respect to the lower deck, above and below the water line the ship would require to be plated all round, to a depth of 5 or 6 feet, and as high as the gun deck. Along those parts, the thickness of the plates would be the same as the armour plates at midships, but gradually tapering to 4 inches thick at the bow and stern. The upper deck, the longitudinal stringers, cells, and plating would extend the whole length of the ship, but would be thicker and stronger at the sides than at midships; and thus, by a careful distribution of the material, duly proportioned, the *maximum* of strength might be, if not entirely, at least approximately, obtained.

I have not entered upon the question of the quality of plates, angle irons, &c.,

necessary to be employed in the construction of ships of war. It has been referred to on former occasions, and clearly shewn that what are called boat plates vary in their tensile strain of resistance from 14 to 17 tons per square inch. This is a low standard of value, and unprofitable in its application, by adding to the weight without increasing the strength of the vessel. In ships of war, and also those for commercial purposes, none of the plates nor iron of any description should be under 20 or 21 tons per square inch; and, moreover, they should be double-wrought, or, in other words, they should undergo as many processes of heating, hammering, and rolling as will give them tenacity and fibre. In the use of steel or homogeneous iron, the greatest care will have to be observed in regard to uniformity of strength, whether it is made from the puddling furnace or on the principle of Bessemer. In the present state of the manufacture, it is difficult to ascertain whether plates of this manipulation are good or bad. I have tested plates of this sort from the same batch up to 22 and 36 tons per square inch; and I have no doubt when the manufacture is further developed, and has attained a greater degree of certainty in the different processes, that steel plates may be used for shipbuilding with greatly increased security.

With reference to jointing, rivetting, &c., I can only state that good material is of little value unless carefully united by an accurate system of sound workmanship; and having consulted Mr. Grantham's Paper, published in the last volume of the *Transactions* of this Institution, I cannot do better than refer the Meeting to the valuable suggestions it contains on that subject.

When the improvements in the construction of guns have attained greater perfection, and when guns of much greater power than those at present in use may be employed against iron-plated ships, it may then become imperative to augment the thickness and weight of the plates. In doing this, it would be expedient to reduce the length of the midship battery, and extend the unprotected portions, in order to maintain the sea-going qualities of the ship, and, at the same time, not to diminish her powers of resistance to strain. This appears to me to be a *sine quâ non* in marine construction, and for this purpose I would suggest that whatever may be the extent of the armour plating, it should not interfere with the ultimate strength of the ship: that the upper deck in every case should be equal in durability and strength to the cellular structure below; and that whatever may be the effect of the enemy's shot, it should not on any account detract from the original strength, power, and speed of the ship.

Viewing the subject in this light, I have taken the liberty to urge upon the attention of the meeting certain experimental facts with which I happen to be familiar, and which apply with considerable force to the construction of war ships. I make no

pretension to the best forms in naval architecture; but taking iron vessels in the forms and conditions under which they are built, I may probably be excused, if in this state of transition I have ventured to elicit facts which bear directly upon the strength, power, and security of the British Navy.

Before I conclude, allow me to direct attention to Capt. Coles's system of cupolas, which, in vessels of war, would be highly advantageous, on account of the facilities which that system affords in revolving the guns and bringing them to bear upon the object of attack. This plan is, however, attended with considerable risk, as revolving turrets, whether conical or vertical, are liable to be damaged by the enemy's shot when exposed to a battery of heavy guns. The machinery, under these circumstances, is liable to get jammed, or crippled, so as to render the armament utterly useless, and expose the vessel, with all on board, to the power of the enemy.

These are considerations which appear to require careful attention on the part of Capt. Coles and the Government, before the plan is tried and confirmed, as the application of twin screw-propellers, by Mr. Richard Roberts and Capt. Symonds, appears to introduce an effective remedy for these evils. On this principle, the ship can manœuvre in any direction, and to any extent; by reversing the motion of one engine the vessel can be turned round, with the whole of her broadside, in about the same time as the cupola with one or two guns. This power of motion in any required direction appears to me to be a desideratum in manœuvring ships of war, and is well entitled to the consideration of the Admiralty, at a time when science and its practical application may place the navy of England on a principle in advance of every other nation.

ON IRON-PLATED SHIPS.*

By J. D'A. Samuda, Esq., Mem. Council, I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 26th, 1863; the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

To possess an efficient navy is, and must always be of the highest importance to this country; and that no navy can be efficient except it be armour-cased, has long become an axiom with those acquainted with the artillery of the day which in all future wars will be brought against it. After a long continued and determined opposition on the

* Received March 26th, 1863.

part of the Exeeutive, the neeessity of introdueing iron-cased vessels has been admitted, and the building of them proceeded with, though with apparent reluctanee, and to an extent only suffieient to balance any advantage that appeared to be daily aceruing to Franee, from her not being trammelled with the same prejudice for bygone systems as was the ease with our Admiralty and their offieial advisers.

With the power of influencing, if not absolutely controlling this great engineering question, and entering upon it under sueh cireumstanees, it is not astonishing that they should have only imperfeetly realized the magnitude of the issues dependent on their deeisions, and should have regarded the matter more in the light of an experiment than of an aseertained necessity, to be met with all the vigour and ability that both the Government and the eountry eould bring to bear on the subject.

If we are willing to pass by the four years that sueceeded the Russian War, whieh were allowed to lapse without improving in any way the experience we had obtained in easing iron vessels with armour, and review the way in whieh this important matter has been dealt with since 1859, it appears to us most unfortunate, that eonditions should have been laid down by the Admiralty, and insisted upon as indispensable, although eondemned by their well-wishers, *viz.*, that the ends of vessels should be wholly unprotected; and that as a result, three morc years have bcen employed in the produetion of four very imperfectly protected vessels.

That state of things has fortunately now passed away; partial protection is no longer upheld as a neeessity, and entire protection, in deferenee to a strongly-expressed opinion, has been substituted in all the frigates which have since been commenced. That great and important new starting point has been attained. Whether in the improved type of the *Warrior* class (the *Minotaur* and her eonsorts), the imitation of the Freneh efforts (the *Royal Oak* class), or the cupola ships (the *Prince Albert* class), this prominent distinction—this unmistakable improvement—I had almost said this avoidance of radical failure, has been recognized and acted upon ; and happy are we as a nation, to be able by the contribution of a few millions of money to set ourselves right on so serious a matter, without incurring the humiliation and disgraee that in all probability would have attached themselves to so lamentable an error, if war had intervened, and the short-eomings and delays of our authorities had been roughly tested.

Entire protection, the greatest possible speed, armour which admits of the easiest replacement, and, lastly, armour which adds strength to the vessel by being incorporated with its structure, are the four great points that eannot be too strongly urged as indispensable to an effieient iron-clad navy.

Two of these, *viz.*, entire protection, and armour which admits of easy replacement, have been recognized in all vessels now building, where partial protection is substituted by armour from stem to stern, and where tonguing and grooving have been altogether abandoned. The necessity of great speed has also been fully recognized and fairly carried out; and I have great hope that the fourth point, *viz.*, the advisability of incorporating the armour with the structure of the vessel will shortly follow. For this, however, I am content to wait.

It is sufficient for me at present that the only navy capable of protecting the country, and on which the sense of the country teaches it to rely—I mean our iron-clad navy—is at last about to be greatly extended; and although I hold the opinion that to case wooden hulls in armour is at best but a makeshift, and that real service and bad weather will lay bare the fallacy of expecting it to be otherwise than a temporary job, and expose the folly of anticipating that a wooden hull, which has never yet been made capable of sustaining the strain of her engines (when of large power, without shaking and damaging the whole fabric), should be found equal to the additional strain of 1,000 tons of armour bolted on her top sides for any lengthened period of working, yet I feel that having neglected, or only very improperly dealt with the question for the last eight years, it is a satisfaction to know that some proper amount of protection is about to be given to the country; and that if the jealousy of the Admiralty will not allow such addition to be made except in their own dockyards, it is far better that it should be made there than not at all.

I therefore hail with satisfaction the expectation of an addition of five iron-cased frigates to our fleet, though they are only wooden hulls iron-cased. The whole number even then possessed will be still far too small for the protection of our shores and commerce.

Having had occasion to refer to this matter to exemplify the subject of my Paper, I cannot leave it without expressing the surprise and indignation I felt, in common with other leading shipbuilders who have all contributed most loyally to advance the success and welfare of the navy, and who did not hesitate to place themselves and their establishments at the disposal of the Government without any adequate profit when the reconstruction of the navy was of imminent importance, to find ourselves referred to by the Controller of the Navy and the Admiralty in terms of censure and reproach, as a reason for their asking Parliament to give back to them the privilege and patronage of again building in their dockyards vessels which had far better have been built of iron than of wood, and in private instead of in public dockyards.

The first instalment of our new fleet being obtained, or in course of construction,

and which, with the last five vessels referred to, will amount to twenty-two first-class frigates, it must be felt that the period has arrived, when it may be profitably considered, whether any and what general improvement in the character of those which will have to follow shall be adopted; and it appears to me that a consideration of the relative advantages of port-hole and cupola ships will lead to the solution of this important question.

It is natural, in the first instance, that every cased ship should be made to resemble, as closely as circumstances would admit, the vessel *without casing* which it was intended to supplant; but, I would ask,—1st. Has not the circumstance of casing the vessel changed the conditions materially? 2ndly. Has not the necessity for casing still further varied the state of things? And, lastly, must not the effect of modern artillery materially qualify the desirability of keeping a perfect resemblance in other matters to the wooden frigates?

I think these all exercise a material influence, and each carefully considered requires great alterations in the construction of vessels (beyond the casing only) to obtain the best result with an armour-clad navy.

1.—The extra weight of the armour involves the necessity of a vessel of nearly twice the tonnage to carry the same guns and obtain the same speed, while this size, and the extra draft of water involved, are, of themselves, serious drawbacks, and to be avoided if possible.

2.—The casing (rendered necessary in a great degree to meet the horizontal shell firing) is only at best a partial protection while pierced with port-holes from stem to stern.

3.—Although I am not prepared to admit that any guns have, up to the present time, been produced that have pierced a $4\frac{1}{2}$-inch armour plate with a shell, which, having gone through *whole*, has exploded beyond the side of the vessel, yet, sufficient has been done to shew the advisability of using guns of the heaviest weight and largest calibre; and no one can doubt that it is impossible to work such guns as conveniently from port-holes as from a fixed platform in the centre of the ship. All these circumstances, then, are reasons why the old frigate is not the best type to be followed under the existing state of things.

It appears to me, that by extending the consideration of the altered circumstances, the substitution of cupolas in lieu of ports becomes an important advantage, and for the following reasons:—

1st.—The cupola diminishes materially the weight of armour required to be carried on the top sides of the vessel. If 4 feet be determined on in both cases as the extent of under-water protection, the cupola vessel only requires a total depth of armour of 11 feet, against 20 feet for the port-hole; whilst the 11 feet

gives to the sides of the cupola total protection, and the 20 feet only yields partial protection to the other, every port-hole being assailable by shot and shell.

2ndly.—The facility for working very much heavier guns, the advantage of moving them mechanically, and the very much greater range obtainable, render every gun in a cupola ship equal to, at least, two guns worked from a port-hole, and in many instances to more than two.

3rdly.—The concentration of the crew, and the extra protection they can obtain under all circumstances, are advantages not to be overlooked.

4thly.—The rolling of the vessel will interfere with the working of guns, where they have to be fired from ports, before it will reach a pitch to prevent working them in cupolas; and when they are fired from over deck.

And lastly, the power which this mode of construction gives of keeping down the tonnage of the vessel, and at the same time obtaining a high velocity, is of the greatest importance.

I know it may be argued that at present it is a matter of experiment or speculation how a cupola will act; that the rolling and pitching of the ship may damage its machinery; that a shot striking at its point of junction with the deck may bulge the plate and jam the cupola, and that on boarding, the same effect may be produced by wedging it with a crowbar; but I think it will be found that in cases where objections go no deeper than to require improvement in mechanical details, they may be safely left to be overcome by the mechanical skill that will be brought to bear on the matter if the principle be correct, and if of sufficient importance to engage the general attention of the engineers of the country. In this case, I think the object to be gained of the highest importance. I am strongly impressed with the numerous advantages which the carrying of guns in cupolas over port-holes affords.

I imagine also that with each increase in the size of the artillery used, a most important element in the discussion of the relative merits of the two systems, the advantages of the cupola become increased; and, it appears to me, that the development of the system will fully repay all the expense and trouble, and will, I think, ultimately lead to a conviction of the general superiority of cupola ships for the service of the navy.

But the importance of obtaining this result at an early period is what I desire; and, if I can sufficiently engage attention to the importance of this conclusion, I shall have attained the object I had in view in writing this Paper. The *Prince Albert* (cupola ship), is an excellent beginning. The design, tonnage, draft of water, and extent of armament, are all, in my opinion, exceedingly good. The engines should, however, have been 800-horse power instead of 500. She could be arranged to carry this power, and the change would give her the advantage of being a 13-knot ship, and most importantly

improve her character. Let the Admiralty decide to build five additional *Prince Alberts* in private yards, at the same time they are proceeding with the five port-hole frigates in the Government dockyards. £1,000,000 of money is all that will be required for this—£500,000 this Session, and £500,000 the next. I am satisfied that the country, speaking through the House of Commons, would cheerfully vote this sum for such an important object; and I am also satisfied that the Government would be as ready to ask it as the House of Commons to vote it, if they realized the fact that I think these vessels when built will demonstrate, *viz.*, That cupola ships, far from being useful only for coast defence, will be found suitable for service all over the world.

ON THE PRESENT STATE OF THE QUESTION AT ISSUE BETWEEN MODERN GUNS AND IRON-COATED SHIPS.*

By J. Scott Russell, Esq., F.R.S., Vice-President, I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 26th, 1863; the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

Of the many important advantages which have arisen from these periodical meetings, there is one which the subject of this Paper brings incidentally before us. These successive meetings form landmarks in the progress of our professional knowledge, and also enable us to judge of the progress which the practical world is making around us. In order to turn them to the best account, both for our own advancement and that of the world, we shall do well to make them occasions, first, of retrospect as to what has been done since we last met, and secondly, of forecast as to the direction which our energies should take in future years, both for the advancement of our professional knowledge, and of the public interests connected with it.

It is for such a purpose that I avail myself of the present occasion to put on record the existing state of our knowledge regarding the great question of the construction of iron-cased vessels of war, with a view of deducing from it by discussion, some indication of the direction in which our efforts may be most advantageously exerted during the ensuing year.

In bringing this subject forward, I think we have a right to congratulate ourselves

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on the results which the past discussions of this Institution have produced, as we find them recorded in the *Transactions* of the two past years. If I look back to our meeting in March of 1861, I find the whole tendency of our discussions to be favourable to the absolute and immediate adoption of iron as the material for war ships, and of the abandonment of wood; but I find, also, that beyond the walls of this Institution, there was a strong opinion contrary to the abandonment of the old material, and consequently an unwillingness to enter with energy on the new system of construction. When I look at the volume of 1861, and find that there were then strenuous advocates for wooden ships, and when I see now hardly any individual who ventures to say more on behalf of timber than that he hopes that combustible and perishable material may still be temporarily employed as a mere expedient, I cannot but rejoice at the unmistakeable progress, both in professional opinion here, and in public opinion elsewhere.

I shall now ask three questions. What were our views at our meeting of 1861, with reference to the nature and construction of our fleet of the future? What are our views now? And what are those we should entertain for the future, in any constructions we might advise or undertake?

After a long and important discussion which occupied two meetings in 1861, and which I was permitted to sum up as the author of the Paper in which the problems had been stated, we arrived at the following conclusions:—first, that speed must be reckoned the quality essentially necessary for victory in modern war—that speed meant greater speed than your enemy—and that for the present it was not wise to give a ship of war less than from 14 to 15 knots; secondly, that the height of ports should not be less than about a sixth part of the beam of a ship, nor nearer to each other than 15 feet; thirdly, that $4\frac{1}{2}$ inches of armour was sufficient to render an iron-plated vessel safer against modern artillery than wooden vessels had been with old artillery. I recommended on that occasion that 8 inches of iron should be provided for, and I also shewed how all the good qualities of an iron ship could be fully provided for with 8 inches of iron armour. The next point we considered, was the extent to which protection ought to be sought and provided in a man-of-war. On this there was some difference of opinion; but it was unanimously agreed that the quantity of armour to be carried should in no case go to the extent of damaging the seagoing qualities of a ship, or to deprive her of the speed necessary for victory; the distinction of course being taken between a mere floating battery and one entitled to the name of a man-of-war, that is, ready to go anywhere and do anything. There were other points, such as wood backing, the necessity of carrying coals for long distances, the expediency of running down an enemy, the introduction of water-tight compartments and double skins as elements of safety as well as strength; and further, there were considerations as to the form of battery to be

used, whether with square or inclined sides, whether revolving or fixed, which were thoroughly discussed; and on all these it is only necessary to consider whether anything that has since taken place, should lead us to alter the views then entertained and the measures then advocated.

On each of these points I shall state shortly my own personal opinion in order to raise the question and have it fully discussed by the Meeting.

First, with regard to speed. All that has taken place during the American war has tended to confirm the doctrine I have always advocated, that speed is the first and indispensable requisite of a successful war-ship, and that if necessary in any degree to other nations, it is much more necessary to the English nation. On this point the events of the American war have given instructive evidence. We have seen a fast, unprotected screw steamer occupy a numerous fleet of the enemy's vessels in the simple duty of pursuing her. We have seen, that for that purpose, neither heavy armament, nor iron coating, nor any other quality, has been of the slightest value. Owing to her superior speed, she has continued to infest the shores, and prey upon the mercantile fleets of the North; she has been pursued, but unharmed, by a whole navy. Let us suppose for a moment that that ship had been still faster, say 14 knots an hour, and still better than she is—that she had belonged to some other country—that our Channel and coasts had been her favourite hunting ground—and that our gold ships coming home from Australia had been her prey. Of what use would our whole fleet have been to us on such an occasion? And imagine what would have happened if the *Defence*, and the *Resistance*, and the *Hector*, and the *Valiant*, had all been sent in search of her; what a lame, impotent, and purposeless chase it would have been. The result would have been, that she would have been everywhere, and they would have been nowhere. Fortunately for us, we have a *Warrior* and a *Black Prince*, and as long as our enemies do not build better, we are safe. I will not say another word, nor occupy another moment of yours, in advocacy of speed: if I have said so much, it is because at that very meeting in 1861 somebody was found to say that it was better to have a slow ship than to sacrifice the armour of a single gun. I hope in this point we have made great progress. Let us only imagine for a moment that the Americans had possessed a single iron ship of 14 knots an hour, with a shot-proof engine-room, she would have run up alongside the *Alabama*, and poured into her the contents of her shot-proof shell battery, and there would have been an instant end of the *Alabama*.

The next question is most important. What is the thickness of armour which an iron-cased ship ought to carry in order to be considered fairly protected? Are we justified in sending into action ships coated with $4\frac{1}{2}$ inches of iron on a wood backing of 18 inches of teak? To this I answer,—Yes; to any weapon which our enemies have got

which they can work in a ship, or which they have ships to carry, our $4\frac{1}{2}$ inches of iron, on 18 inches of wood, holds good. It is proof against our 68-pounder naval gun, and also against our 100-pounder rifle gun, and therefore against the naval artillery of any other naval power. This, I think, is the fairly practical inference to be deduced from all our experiments at Shoeburyness and elsewhere.

Here it is proper, perhaps, to raise the question what we mean when we talk of armour *proof against shot.* Don't let us mean by proof against shot, *absolute impenetrability.* That is a dogmatic expression merely, the consequences of which ought on no account to find their way into practical application. *Absolute invulnerability* is a mere fiction, like most other absolutisms. War ought to have its risks, or it ceases to be war, and becomes merely a game of mechanical chess. So long as war is war, it must mean danger, misfortune, and death. I think, therefore, I am justified in this conclusion, that the armour of the *Warrior* and the *Black Prince* may be considered shot-proof. Men who fight these ships against existing naval artillery will run less risk—will be able to hold out much longer than in the old days of wooden ships, before naval shells were invented. Fleets will fight, but not with impunity. In short, although we are no longer justified in expecting our men to work their guns in a wooden ship, it would be cowardly not to fight a battle as bravely as ever in the *Warrior* or the *Black Prince.*

So much for the ships we have built. The next question to be raised is,—What about the ships we ought now to build? Are they such as we should have built in 1861, or are they different? Now, it must have been observed in the progress which has taken place in the construction of artillery, and in that of iron armour, that whenever a step has been gained in giving force or penetration to guns, there is an immediate cry raised by the advocates of the "do-nothing" and "wait-a-bit" systems—a cry of helplessness, "What shall we do next? Artillery grows stronger and stronger, "and if armour has to grow thicker and thicker, how shall we ever find ships to carry "it?" And then comes the wonderfully illogical conclusion,—"We shall have to go back "to wooden ships after all."

Fortunately, it is our business to face these difficulties, and to take the measure of our enemy—not to run away from him. I will proceed, then, to measure our enemy, and next to consider the steps by which we may get round him, and be too much for him. What, then, is the present state of artillery? What is the *worst* it can do? Has it done more than we anticipated in 1861, and had reason to provide for? I may observe, that in this respect we cannot be too grateful to the Iron Plate Committee for the enquiries they have made, for the scientific and systematic manner in which they conducted those enquiries and for the publicity which has been given to the valuable experiments at Shoeburyness; and though we may regret that the narrow policy of a part of the

administration of the public service has prevented a full and authentic publication of their results, a sufficient amount has appeared in the organs of public information to make us feel sure of what we are about. I believe I do not violate any official confidence when I say that a member of that Committee, Mr. Pole, an eminent engineer, very early gave us a law by which to estimate the damaging effect of the shot, and shewed it to be truly represented by the weight of the shot multiplied into the square of its velocity—a formula which we all use as the measure of what we call the work to be done by a mass of matter in rapid motion. On the other hand, he very early deduced from the experiments this general result,—that the resistance of the plates to the shot would be in the ratio of the square of the thickness of the plate, the plate being sound and good. Unluckily, however, the rigidity of the plate, or its liability to be cracked, increases as the cube of the thickness, which explains to my mind the necessity of having a very soft iron, and that the thicker the plate the softer it should be—conditions which are contrary to the present state of the manufacture.

Now, if we look at the results of this formula, which I remember Mr. Pole laid down in 1861, we shall have the following conclusions,—first, I take for granted that a 4-inch plate of the best maufacture is about a match for the 68-pounder, and that the half-inch added to the four, turns the balance decidedly in favour of the plate, and makes it shot-proof. Next, I take the 68-pounder, as fired with 16lbs. of powder, and as obtaining a striking velocity of 1,600 feet per second, as our standard of the working power of that shot. I will now take double that shot, or 136lbs. as the weight. I will suppose it fired with powder enough to give it in like manner 1,600 feet per second, which is certainly the highest practicable velocity, and I find the result as nearly as possible $6\frac{1}{2}$-inches. A $6\frac{1}{2}$-inch plate, therefore, will be shot-proof to a 136-pounder, as much as the $4\frac{1}{2}$-inch plate is to the 68-pounder. I will next take a 200-pounder shot, which is almost exactly three times the 68-pounders. I find that a 7-inch plate is as strong against this, as the 4-inch is against the 68-pounders, and therefore $7\frac{1}{2}$-inch plate may be considered proof against a 200lb. shot. I next take a 270-pounder; the damaging effect of this is balanced by the resistance of an 8-inch plate, and therefore an $8\frac{1}{2}$-inch plate would be proof against it.

I have thus brought down these calculations of two years ago to the present state of artillery, containing all the improvements of Armstrong and Whitworth to the present time, and I now proceed to show how they square with the results of our latest experiments. The other day at Shoeburyness, Armstrong's 300-pounder was nearly a match for the $7\frac{1}{2}$-inch plate; it did not go through it, but fell outside. It did not make a hole through it, it pushed the piece it struck very nearly out of its place in the plate, but left it sticking fast, plugging up the hole. Its velocity, however, was below the

standard velocity I have taken, but, on the other hand, the ball was not round but a massive elongated rifle steel bolt.

From this it appears, that in the latest artillery experiments, the shot has done its proper work, and neither more nor less than was anticipated, while, on the other hand, the plate has done its proper work, and as much as we ever expected.

I will now proceed a step further, and anticipate the progress which our artillery may be expected to make. I will take a 400-pounder: the 10-inch plate will by the same law be a match for the 400-pounders; and if, I suppose we obtain a 600-pounder, then the 12-inch plate will be a match for it.

We may consider, then, the following as our list of shot-proof plates for the present and the future:—

	Thickness of shot-proof plate.	Weight of shot.
Present	$4\frac{1}{2}$ inches.	68 lbs.
	$6\frac{1}{2}$,,	136 ,,
	$7\frac{1}{2}$,,	200 ,,
	$8\frac{1}{2}$,,	270 ,,
Future	10 ,,	400 ,,
	11 ,,	500 ,,
	12 ,,	600 ,,

It will be seen that the latest experiments at Shoeburyness entitle the above table to our full confidence, and I cannot leave the question of what we have done in artillery without observing that these last results are as yet the results of exceptional pieces, and not of accepted artillery. Much progress must be made before we can reckon them as parts of the working battery of a ship; but that time and mechanical ingenuity will furnish us with guns of this calibre, and that mechanical means of working them will also be found, no thoughtful man who watches our progress will venture to doubt, and no prudent man will hesitate in setting about taking measures of protection to meet them.

With regard to the artillery, which I suppose to range from a 400-pounder to a 600-pounder, what I have already said of the 300-pounder as a naval gun applies still more strongly to the classes we have imagined. There is no difficulty in building a big gun, provided you don't work it with a high charge of powder; the real difficulty is in making the bigger gun more effective than the smaller one. All our experience shews that it is the *speed of the shot* which tells; and its power of doing work, that is, of doing damage, increases as the square of its velocity; so that gain of speed is much more important than mere size and weight of shot. With regard to a great gun, we are so rapidly approaching the extreme limit of the power and endurance of iron, that the difficulty of maintaining the speed of the projectile, consistently with the security

of the gun, is becoming enormous. We shall make big guns, therefore, and we shall cast big shot, but the real difficulty lies in enabling these large guns to work continuously with safety under the large charges of powder which are necessary to give high speed.

I will now look at the difficulties which in like manner beset the manufacture and use of thicker armour plate. The experiments already made at Shoeburyness have certainly shewn that Mr. Brown, of Sheffield, can make as good an armour plate $7\frac{1}{2}$ inches thick as ever was made of $4\frac{1}{2}$ inches; and as all I ask to meet the heaviest projectile up to the present moment is $8\frac{1}{2}$ inches, I think no one will doubt the practicability of the manufacture of iron armour plate possessing a power of resistance equal to the highest power of attack known at the present day.

But it will be said, "Armstrong promises us 400, 500, and 600-pounders." To this I merely reply, that before he has produced them Mr. Brown will probably have supplied to the Iron Plate Committee the 10, 11, and 12-inch plate necessary to meet them.

Hitherto we have talked only of our respective powers to make large artillery, and to make thick armour plates to meet them, and these two lines of progress have gone on just as we expected they would, *pari passu*, and we may expect them to go on at the same pace for the future; but a new question arises in regard to both,—Can you use them? To make great guns is easy, but can you find men and machinery to work them? To make large plates and heavy armour is easy, but can you find ships to carry them? And in carrying them, can you find ships able to maintain high speed and proper behaviour at sea? These are practical questions, and both are capable of a plain practical solution.

First with regard to the guns,—Can you work them? I believe that the Ordnance Committee has decided, or the naval authorities (I don't know which), that the future naval gun must not weigh more than 6 tons, nor carry more than 35 lbs. of powder. If it be so, I will venture to call it a 120-pounder, and then, the $6\frac{1}{2}$-inch plate is more than a match for it. If there be this limit to the size of guns that are to be worked by hands in ships at sea, then I may consider my ship, with $6\frac{1}{2}$-inch armour, good against all comers armed with the new naval gun.

But we are all certain that guns of heavier calibre than this will assuredly be sent afloat, and whilst afloat will be loaded, pointed and fired. It would be wise, therefore, instead of shutting our eyes or blinking the question, to look it steadily in the face and meet it. How those large guns are to be worked is a question long ago met by the Americans. In the original design of the Stevens' Battery, which has its place in our *Transactions*, each gun is balanced on a turn-table, is made to revolve by machinery, is depressed and loaded by machinery placed below the turn-table, and merely receives its delicate final adjustment by hand. To a revolving gun on a turn-table, revolving armour plate is necessary; and whether we have it in the shape of a cylinder open at the top, or

a cylinder closed at the top, as the Americans have it, or a semi-circular dome as Captain Coles originally had it, or in a conical form, as I employed it in the original cupola which I planned and constructed for Captain Coles, is a mere question of suitability and convenience ruled by special purpose; still it appears certain that with revolving guns balanced on the centre, placed on a turn-table, and revolving by machinery, a revolving shield is the only convenient form of defence.

That the revolving system is the right one for vessels intended to have very few very heavy guns, I have no kind of doubt; but, to my mind, the limit to the size of ship on which the cupola should be used is where only two shields covering two or four guns are to be used. When more than two or four guns are to be employed, I find it wise to pass at once from two revolving shields to a fixed close battery, and the reason of this is, that the same quantity of armour and height required for the protection and working of a ship with two shields, will protect and work much more comfortably ten guns in a fixed battery.

But the question arises, how are ten guns to be arranged and worked in a broadside battery with sufficient horizontal training, elevation, and depression without exposing numerous and large ports to shells? And how are broadside guns as large to be worked by machinery in a fixed battery as they are on a revolving turn-table and shield. On all this I can only say that I have no doubt that those who back the guns have sufficient ingenuity to work them. For my part, I feel no more doubt in being able to work these heavy guns easily and comfortably on board ship, at broadside ports, by mechanical means, than I originally felt when Capt. Coles's shield was brought to me to be worked by mechanical means.

I am, therefore, giving the large guns at once the full benefit of being well managed, and well and safely worked on board ship, and I pass to the other question,—Can we manage to carry armour plate sufficient to defend our ships from such guns, as well as to carry them?

Allow me at the outset to remind the Meeting that we are not yet near the limits of thickness and weight of ironside which ships of existing sizes are able to carry. I beg leave to remind you that in my Paper of 1861 and the debate which followed it, I took as the basis of all my calculations that it would be necessary to carry 8 inches of iron protection, over and above the thickness of the ship itself. At that time we had no experience of anything but wood backing, and therefore we were obliged to allow out of this 8 inches some estimated weight for wood backing and fastenings, and their appendages. I think we are all now satisfied (except perhaps the Lords of the Admiralty), that wood backing is a delusion and a snare, and that the strength to resist the shot is wanted, not at 18 inches from the front of the plate, but in absolute contact with the plate itself. In short, that we must have *iron* backing, and whether that iron backing

is to be applied in my way, or Mr. Samuda's, or Mr. Fairbairn's, or some other way, is the only choice left to the authorities.

This being once resolved, the difficulties disappear. If iron backing be substituted for wood, we can carry 8 inches of solid iron protection, combined in whatever way may be found most effective, and the figures will stand as follows:—

Vessel to carry $4\frac{1}{2}$-inch armour and $3\frac{1}{2}$-inch iron backing.

Length	...	400 feet	H. P. ...	...	1,800
Breadth	...	60 „	Tonnage	...	7,200

A vessel of these dimensions would be very little larger than the enlarged *Warrior class* now building by the Admiralty; she would be faster, carry more coals for a longer voyage, and gain in every way by the omission of the wood backing.

The question, however, still remains,—To what resistance are $4\frac{1}{2}$-inch plate and $3\frac{1}{2}$-inch iron backing equal? The answer has already been given by experiments at Shoeburyness. A single target has stood twenty-six shots of various kinds up to 200 lbs. weight. It has withstood solid wrought iron Armstrong shot from the 300-pounder with 50 lbs. of powder, and it still stands where it did. Mr. Whitworth has kindly promised me the favour of delivering his shell against such portions of it as still remain unbattered, and although he has never yet made up his mind to fulfil the promise, I have no doubt he means to do it, and I have as little doubt of the result. But that is mere opinion, not fact; and I therefore go back to the actual fact, which is, that although that target has suffered a cannonade unparalleled in the history of target experiments, and although it is much damaged, yet every shot fired at it was found on the *front* of the target—no single shot *passed through the armour*, and the ship's lining inside was found to give an absolute immunity even to the danger arising from the fragments of the damaged plate and shot which were stopped by the lining.

We are safe, then, I consider, against a 150-pounder, with our present size of ship and strength of iron-backing, and I now come to the contingency which stares us in the face, and which has ripened into a strong probability by the experiments at Shoeburyness last week. We have seen that the Armstrong 300-pounder was a match for the $7\frac{1}{2}$-inch plate with wooden backing. I may safely conclude, therefore, that 7-inch armour with iron backing would be much more than a match for the 300-pounder. If this be so, we must certainly build a larger ship than we have yet built, in order to carry an entire shot-proof broadside over her entire length. Such a ship must have the following dimensions:—

Length	...	500 feet	H. P. ...	..	2,000
Breadth	...	70 „	Tonnage	...	12,000

She would have all the sea-going qualities of the *Warrior*, would sail faster, go further, and carry a much more powerful armament.

To include the future and face the worst, let me suppose Armstrong's success to have equalled his most sanguine expectations, to have produced a durable, safe, and effective 600-pounder, and to have obtained from it the full striking velocity of 1,500 feet a second, and that we must carry for that purpose 11 or 12 inches of armour on suitable iron backing. Is a ship of war, with an entirely protected battery on such a scale, practicable or impracticable? I answer, that that is exactly the *Great Eastern:* that ship cut down in height, and carrying a row of broadside guns along the whole of her length, entirely coated, with the exception of the extremely thin and narrow part of the bow, which it would be useless to load with armour, would be just the ship to carry a broadside of 600-pounders, and to keep out every shot which an equal enemy could fire.

But it must not be supposed that because we have got heavy guns and must have thick armour plate, that therefore we can have nothing but large ships. We can have small ships, by limiting the extent of two things—the battery and the protection; that is, by adopting the two principles of partial battery and partial protection.

By *partial battery* I mean that instead of carrying the battery the whole length of the ship, we should only carry it through a portion of the length, being the system which I adopted in my original *Warrior* design of 1855, where I limited the shot-proof battery to the centre and after-part of the ship, but stopped it short by a shot-proof bulkhead, so as to leave the whole of the fine sharp bow unprotected. This system was adopted and further extended in the present *Warrior*, by removing the battery from the stern as well as the bow, and confining it to the centre of the vessel.

In this way the limitation of the length of the battery enables us to diminish its weight, and in like manner the limitation of the breadth of the battery enables us also to diminish its weight without injuring its effectiveness, and even with means to increase its effect. Another mode of accomplishing a limited battery is to plant several small ones at convenient points on the deck of the ship, as has been done in several of the American vessels; and finally there is the system of Captain Coles and Mr. Ericsson, who use revolving batteries in the shape of towers, shields or cupolas. All these may be said to constitute a system of partial or local batteries, which go to reduce the quantity of armour required for the protection of the guns and the men.

The next mode of reducing the quantity of armour is by the system of *partial protection.* We have seen in the American war how much a vessel that has superior speed can do, even without protection. Now, if you will conceive an iron vessel which would go a mile an hour faster than the *Alabama*, only thoroughly protected over her engines, boilers, magazines, and rudder, with all the rest of her unprotected, even including the guns and men, I think you will agree that in such a vessel a smart English captain and crew would make short work of the *Alabama.* Now, such a degree of

protection could be most easily obtained against guns of any size, without either diminishing the speed or injuring any of the good qualities of a small ship, and it is easy to obtain this amount of protection and this quantity of speed in that class of vessel which, in my "Fleet of the Future," I have called the steam clipper or ship of the fourth class.

If further protection be desired let us estimate its further value. Having secured engines, boilers, magazine and steerage, what is the next point in armour for which you require protection? Naturally I presume it to be the guns and the men, although I am not sure that both guns and men on an open upper deck might not be left with tolerable safety to take their chance, in a very fast vessel in which the men were quite certain that the boiler under their feet could not be blown up: it appears to me that the whole course of the American war proves that men ran far more risk from this source than any other. Nevertheless I will take this as second in order, and say that we protect also the battery. Thus we have now the whole centre and fighting part of the ship protected.

What, then, are we to do with the ends of the ship? I answer, if you cannot carry the armour, your course is easy. Let all the decks and all the partitions, subdivisions, and bulkheads between wind and water be perfectly water-tight. If this be done, it will take a very long time and abundance of unoccupied leisure to enable your enemy to disable you, the probability being that he is in the same condition as yourself, or is in some other respect your inferior. If, however, your enemy is entirely coated, but slow, you can choose your own time and way of attacking him. If, on the contrary, he is entirely protected, and as fast as you, he will be many times your size, and therefore an overmatch.

The next point in order after the protection of the men and guns, is the water line, or the parts of the ship between wind and water. This leaves the upper part, fore and aft entirely unprotected; but by protecting the water line for a certain distance above and below it, the perfect form of the ends of the ship may be preserved, and the shot and shell of the enemy will only be able to injure the upper parts and the quarters of the men, who will all be drawn off into the protected part.

If more protection be wanted, it could be given to the upper works of the ends of the ship; but that would amount to complete protection, and would admit of a battery the whole length of the ship. I have omitted one kind of partial protection, as I hope no one but its two noble inventors will ever think of repeating it, even though *Hectored* into it by its *Valiant* champion. It seems to me a kind of protection only fit for fools and cowards. The upper battery and the men are entirely protected by armour from end to end, but the whole height of deck under their feet throughout the two ends of the vessel is left unprotected, so that the men have this comfort, if they know it, that

they cannot be hit by a direct shot, but that they are sure to be blown up from beneath, along with the deck on which they stand, by the first shell which explodes under them.

The conclusion, therefore, which I draw from the discussion of the relative conditions of naval artillery and naval shot-proof armour is, that the improvements of the one are being met with equal rapidity by improvements in the other—that the limits of the power of guns to give high velocities to heavy projectiles, appear likely to be reached long before we are stopped in our powers of protection; either by inability in the manufacturers to make iron armour plates large enough and good enough, or by the incompetency of iron ships and iron backing to support that armour strongly and keep it in its place securely, or by the inability of ships, no larger than those now afloat, to carry adequate armour and armament, without the loss of high speed and perfect behaviour at sea.

ON IRON-CASED SHIPS OF WAR; INCLUDING A DESCRIPTION OF H.M.S. "ENTERPRISE," AND SOME REMARKS ON SEA-GOING SHIELD SHIPS.*

By E. J. Reed, Esq., Mem. Council I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 26th, 1863; the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

It is with great satisfaction that I avail myself of the present opportunity of laying before this Institution, in which so many professional shipbuilders and naval officers of distinction are assembled, the views which I entertain, and upon which I have sought to act, in reference to our iron-cased ships of war. Although I have taken, as you know, an anxious interest in the welfare of this Society from the moment of its establishment, I have on no former occasion yielded to the advice of those who have requested me to read Papers here, because I have been unwilling to embarrass myself, as your Secretary, with any other than official duties during our annual meetings, and also because I did not wish to assume on such occasions any greater prominence than was unavoidable. As I have now placed my resignation in the hands of the President and Council, I feel free to address you without undue restraint, and to assist, in so far as I may be able, at your deliberations upon the important questions that we have to discuss.

I propose on the present occasion to lay before you a few considerations concerning iron-cased ships of war, noticing first some features of war-ship construction which

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appear commendable; next, the way in which I have endeavoured to embody those features in two or three vessels of war designed by myself and building under my superintendence; next, the criticisms which have been passed upon those vessels by one or two persons; then the difficulties which lie in the way of the exclusive adoption of the revolving-shield or turret principle; and, finally, some of the directions in which, in my judgment, improvements must be carried out.

I will speak first of a few general features of construction which seemed to me worthy of adoption. These are: that we should employ iron armour of some kind, and to some extent, in every class of fighting ship that will carry it, large and small; that we should employ a few large guns wherever practicable in preference to many small ones, and give these large guns as great a range of fire as possible; that every class of ship should be protected with armour throughout her entire length in the region of the water-line; that the rudder-head and steering apparatus should be protected; that every vessel intended for sea-going purposes should stand up well out of the water, be well lighted and ventilated, and carry efficient masts and sails—in fact, be as unlike the ill-fated *Monitor* in all these respects as possible; that every such vessel should be made strong enough to stand the shock of being used, upon an emergency, as a ram against vessels of her own class; that small war vessels, if armour-plated, may be built of wood, but that when a very high speed or very large dimensions are required, we should build in iron; that when built of wood, the hull should be made solid throughout in the wake of the armour; and, finally, that every sea-going ship of war should be so formed and have her weights so distributed that she will be well supported, as far as may be, at every part, and have no heavy overhanging parts to cause her to strain and work when knocked about in a sea-way.

These are not by any means all the principles that commend themselves to my mind, but they are all with which I need trouble you at this moment, and I will now notice them very briefly in succession. As regards the first of them—the employment of armour in all classes of ships that will bear it—I would remind you that when we met here last year no iron-plated sea-going ship of much less than 4,000 tons burden had been commenced in this country, although it was manifest that if shell-fire would rapidly destroy a large wooden ship it would destroy a small one even more rapidly, owing to the greater fragility of her timbers and planks. The construction of unprotected wooden frigates, corvettes, and sloops had been stopped altogether, but no satisfactory method of armour plating such craft had been laid before the Admiralty. That such a method was desirable, however, was not at all doubted, I presume, and I think I need not detain you, even for a moment, to discuss the point.

Nor need we dwell for more than a moment on the next point,—the substitution of

large guns for small. I have, it is true, met with a naval officer here and there who still prefers a row of 18-pounders to a couple of 110-pounder shell guns; but such a preference is exceptional, and to my mind whimsical. The general bias of the service is unquestionably in favour of big guns; and the bias in favour of securing a great range of fire with these big guns is scarcely less strong or less general. In fact, mere common sense is almost sufficient of itself to decide, without the aid of professional skill, that one heavy projectile of a given kind, whether spherical or elongated, must be as formidable an instrument of offence as several projectiles of a similar kind but of very much less weight. It would not be fair, as we shall see presently, to estimate the value of projectiles of different kinds solely by a comparison of their weights, but where all are of one kind, the heavier projectiles, although fewer in number, are almost without exception preferred.

In reference to the next feature—the protection of the ship with armour in the region of the water-line throughout her entire length—opinion is, perhaps, somewhat more divided; for while some condemn the *Warrior*, the *Defence*, and other like vessels, in unmeasured terms because they are protected for a portion of the length only, others consider the want of armour at the extremities of little importance, while others again claim for it a positive advantage. I for one have never expressed any strong opinions upon the point, but I have endeavoured by my writings, and by my remarks here last year, to show that they are greatly in error who have condemned the *Warrior* without measure because the armour stops short of the bow and of the stern; for I agree entirely with the Right Hon. President (Sir J. Pakington) in believing that the water-tight bulkheads and decks of the ship are so arranged as to prevent any alarming injury resulting from the penetration of the ship at those parts. But at the same time I believe it is better to keep the sea out of the ship altogether if possible, more particularly in war-ships built with superior speed, because one of the very first effects of penetration at the water-line, and of the consequent admission of water, would probably be the loss of that excessive speed to which we justly attach so much importance, and to secure which we strive so earnestly and incur so much expense. On this account, as well as for other reasons which I will not stay to mention, it seems highly desirable to protect our ships from end to end in the vicinity of the water-line.

It may be well to observe further, that the armour which we put on at the water-line helps us materially to accomplish our next object—the very important one of protecting the rudder-head and steering apparatus. I confess that I have always been unable to look with complacency, or even with toleration, upon the exposed rudder-heads and steering appliances which we went on fitting in our men-of-war until only a year or two ago. The persistence with which this evil and dangerous feature of our

war-ships has been preserved year after year completely fills one with astonishment; and when we consider the disastrous consequences which a single shot might have produced even upon our largest ships of the line because of this vicious exposure of their rudders, we ought, I think, to be grateful to Admiral Robinson, the present Controller of the Navy, for the decision with which he has abolished so bad a practice. I am glad to tell you that in every vessel laid down in Her Majesty's Dockyards during the last year or two this protection of the ship at the water-line, and of the rudder-head and tiller by means of armour, has been insisted upon by the Controller, and is being carried out, in my opinion, in a satisfactory manner.

I come next to the preference which I have expressed for thoroughly efficient sea-going war vessels as compared with those wretched, low-lying, ill-ventilated, wave-washed, unseaworthy abortions—*Monitors* forsooth !—which are struggling along the coasts and up the rivers of America, and which, even if tolerable for such objects as the Americans have in view just now, will add not a jot to their power on the seas when the present war is ended. All our national instincts and interests conspire to warn us against the adoption of any and every scheme which would render the war ships of Old England unfit to cross the seas in pride and confidence. Our march is o'er the mountain wave; our *home* is on the deep; our flag

"Has braved a thousand years, the battle *and the breeze.*"

And if any thought, or word, or act of mine can have weight, now or hereafter, directly or indirectly, in shaping in any measure the future of the British Navy, it shall be employed in resisting every approach to a surrender of that power and predominance upon the open ocean in which we have gloried for ages past, and hope to glory for ages to come. I wish to insist upon this somewhat urgently, because we are tempted in many ways, and by many persons, to compromise the seaworthy character and sailing qualities of our men-of-war. Ships without a mast or sail; ships with open upper decks not half-a-dozen feet above the water; ships without a cabin in which men can inhale a breath of fresh air, and without a mess-room in which they can eat a meal decently; ships which are much more likely to carry our flag down to the bottom of the ocean than to bear it proudly over it to distant climes—ships of this sort, I say, are continually thrust forward as great improvements by ignorant or designing persons, and not unfrequently find enthusiastic advocates. I trust, however, that we here assembled are agreed at least in this,—that the war fleet of England should consist mainly of vessels in which our noble seamen, of all ranks, can live healthily and happily, and seek the open sea at all times with security and confidence.

I have next said that it seems well worth while to make our ships strong enough to enable them to be used, if necessary, as rams,—not, of course, against ships very much

larger and stouter than themselves, unless the ram be built especially for that purpose, but against vessels, say, of their own class. I do not consider it likely that many of our existing ships of war will ever be practically used in this way, for they are incapable of turning rapidly, and no enemy would be likely, under ordinary circumstances, to lie still and receive a blow from them when it could be avoided by simply moving ahead or astern. Nor do I think the wholesale destruction of ships by ramming them will ever be a favourite system of warfare among European navies. Still, the power of delivering a blow with the ship herself as a ponderous projectile would be so desirable under many circumstances that we have, I think, done well in constructing our ships so that they may give such a blow with impunity.

I do not think there will be much difference of opinion among moderate and practical men concerning the next statement, *viz.*, that we may with advantage, under existing circumstances, build the hulls of our small armour-plated vessels of wood; but that enormously large ships, and especially ships that are to be driven at very high speeds, must without exception be built of iron. This is a subject upon which it behoves one to speak with unusual care and guardedness just now, and I shall, therefore, confine myself strictly to the statements that small ships may have hulls of wood, and that very large and fast ones had much better have hulls of iron. As to intermediate classes, such as have lately been the subject of controversy in another place, it may be well to say nothing here. When we want a ship to perform the service allotted to our sloops and corvettes in all quarters and corners of the globe—when we want a vessel to go steaming in and out harbours, and up and down rivers, and to go feeling her way over unexplored grounds, then I have not a moment's hesitation in deciding that she may with great satisfaction have her hull built of wood. I am not going to say I condemn iron altogether as a material even for ships of this kind, but neither am I going to condemn wood for the purpose, and I say it would be mere idle theorizing to deny that wooden bottoms are exceedingly valuable in small war-ships designed for foreign service. But then, on the other hand, if we wish to build a ship that shall be driven, say, at 14 knots of speed, there is not one among us, probably, who will doubt that iron is by far the best material for our purpose. It is only just to myself to state most distinctly my preference for iron under such circumstances, because, from the fact that the first vessels built by the Admiralty from designs prepared by me happened to be of wood, some persons have fallen into the error of supposing that I am averse to iron ships. No greater mistake could be made. The very first design submitted to the Admiralty by me, was for a high-speed iron-cased ship of iron, and I have had in hand for some time past other designs which are to be of iron, and in the carrying out of which I have had the honour to receive great

encouragement from the Controller of the Navy. For the truth is, there is no actual difference of opinion at all, that I can find, on this important question. Everybody is thoroughly convinced that for such colossal and fast vessels as the *Warrior* class and the *Northumberland* class, iron is not only the best material, but the only material that we can wish to use, and I never yet met with any one who questioned that fact. No one ever proposed, I believe, to build such ships as those of wood. But then it would be utterly vain and futile to deny in this place, and before this assemblage, that great manufacturing difficulties and imperfections exist in connection with iron ships. At our very first meeting, Mr. Scott Russell, in one of the ablest speeches ever delivered upon iron ships, made this remarkable statement: he said, "The surveyors of Lloyd's "looked over a ship with me the other day, which ship, I think, was only five years old; "and in the middle body, and at the bottom of the ship, the number of rivets that had "*entirely disappeared* was to me astonishing." "I leave it to wiser men than I am," he added, "to find out why they were gone. But the rivet heads were gone. . . A thousand "rivets were gone." One of Lloyd's chief surveyors, Mr. Martin, a gentleman of un- "equalled experience, in speaking of the deterioration of iron ships, then said, "We have "had in some cases *to replace the whole plating of a bottom*, which was $\frac{14}{16}$ in thickness, "some of the plates being wasted through at an early age, the rivet heads being entirely "gone, and the edges of the plating wasted away to the first row of rivets. Had there "not been a second or double row of rivets, the consequences would have been most "serious." At our meetings of last year, we had placed before us statements of even a more striking and general nature. Mr. Grantham, who knows the private ship-building establishments intimately, read us a Paper on the subject, in which he spoke in the strongest terms of the defective systems of work pursued there. He said, "In "iron ship-building, the ordinary system is to fit the joints by rude means, bringing "them as close as is thought necessary, and by the caulking tool to do the rest, which "in many cases amounts to nothing more than *the concealment of defects*." Again, he said, speaking of the rivetting, that owing to defective workmanship the rivet holes are very much distorted, these holes are consequently not filled up by the rivets, and that the rivets when severely tested become loose. "It is evident," said he, "that "wherever a vacancy occurs, however small it may be, the efficiency of the rivet is "greatly reduced; and, supposing further,—*a case which occurs every day in our very best* "*ships*,—that in the same seam both the rivets and joints have the defects above "described, how greatly must the general strength of the ship be diminished!" These statements, and many others of like tenor, have been addressed here by professional men to professional men; they have not been disproved, they have not even been questioned; they have been accepted as true, reported verbatim, and deliberately placed on record in our *Transactions*, for the guidance of all who may do us the honour

of accepting our evidence. There are, then, these difficulties to be considered. But, having said this, I am glad to say also on the other hand, that the imperfections of iron ships are being gradually and even rapidly reduced. I have lately gone most carefully through the works of Messrs. Laird, at Birkenhead, and some of our other leading private ship-builders, and I assure you that neither labour nor capital is being spared to turn the work out of hand with a high degree of excellence.

But, whenever the hull is of wood, it should, in my judgment, be made solid throughout behind the armour, and not be left with openings between the timbers of the frame, as has sometimes been the case. This is a point to which I attach much importance, because by filling in the frames we get several great advantages with a very small increase of material. Not only do we gain an enormous increase in the structural rigidity or stability of the fabric (especially if we dowel the frames and fillings together); but we also render the whole side one solid mass, from the outer plating to the inside plank, and thus, instead of admitting the sea into the ship when the outer plate and plank alone have been broken in under fire, we exclude it effectually until the plating and some *feet* of solid timber have been penetrated through and through.

The last of the features of construction which I mentioned favourably at starting—that of an equable distribution of weight and of buoyancy throughout the ship—is one which was most ably insisted upon at our first meetings by Mr. Scott Russell and by Mr. Grantham. "The first rule," said Mr. Scott Russell, "that we ought to lay down in "building a good ship, is that the weights placed on board the ship should be distributed "in uniform proportion over the buoyant portion of the vessel. Therefore, as a first "axiom and principle, if you are going to build a ship with fine ends under water, let her "have fine ends also above the water." Mr. Grantham said, "It is quite clear that a "vessel should be so constructed, and if possible so loaded, that when in smooth water "the weight should as nearly as possible correspond with the displacement of every "portion. She will evidently then be in the best condition to sustain the action of heavy "seas, and the unavoidable strains which these occasion will be reduced to a minimum." To these views I not only give my assent, but I believe them to be applicable with great advantage to men-of-war. It is well known that we have gone on for many years in utter disregard of them, ignoring them more and more, in fact; for as we have increased our speed and the size of our guns, we have gone on fining the bow below the water, and filling out above to get fore and aft fire, until we have rendered everything like easy motions and speed in rough water impossible. Directly we attempt to drive our fine wooden frigates at full power over waves, their heavy and burdened bows plunge them down into every wave that approaches them, and the ship is thus brought almost to a standstill every few seconds. This is manifestly a great evil, and it can only be avoided

by such a relative adjustment of weights and of displacement as that adverted to above. I ought, however, to state that the removal of guns from the extremities, and the carrying of the anchors further aft has been carried out systematically during the last two years. It is also important to observe that by concentrating the weights near the centre of the ship and keeping the extremities light, you greatly increase the facility with which the ship obeys her rudder.

I come now to notice the manner in which I have sought to embody the features before mentioned, in the *Enterprise* and some other vessels. I will mention the *Enterprise* first; and I ask you to observe with care the description I shall give of her, for a reason which will appear presently. I would remark in the first place that having urged the protection of small vessels upon the attention of the Government Constructors at Whitehall for some time, without the slightest wish to put myself forward in the matter, and having at length been referred by them to the Controller of the Navy and the Board of Admiralty, I put my views upon paper, and submitted them officially. From that moment to this I have found both the Controller and the Board willing to give me all necessary assistance in forwarding the object in view.

In my official communications I expressed my conviction that even the small 950-ton sloops of war were capable of receiving a very useful amount of armour plating, and after due consideration they took me at my word, and gave me the *Enterprise* to build. The frame timbers of this vessel were to a large extent converted, so that I laboured, of course, under some considerable difficulties, a fact which, if I may say so, my critics have sometimes kept out of sight. The principal features of the *Enterprise* were designed in this way: In the first place I fixed upon four 110-pounder shell guns as a sufficient armament to replace the numerous small guns which the ship would have carried if completed as an unprotected wooden ship. These four large guns I determined to place in the centre of the ship, in order to give them, and the armour which was to shield them, the support of the buoyancy which abounds at that part of the vessel. Upon the sides of the ship I placed $4\frac{1}{2}$-inch armour to protect the guns, extending it from a sufficient height above, down to the neighbourhood of the water-line. Below this armour I found I could place a tapering belt of armour plates, reaching from a foot or so above the water-line to 3 or 4 feet below it, making it $4\frac{1}{2}$ inches thick at the upper and somewhat less at the lower edge. This belt I extended over the whole length of the ship, from stem to stern, raising it an extra foot or two at the stern to shelter the rudder-head and tiller. To prevent the battery from being raked, I fitted transverse bulkheads at its extremities, just as such bulkheads are fitted in the *Warrior*, and for precisely the same object, and over the guns I fitted a solid roof or deck, surfaced with iron, to protect them and the gunners. I next raised the decks a foot or two in order to bring

the lower deck above the water, and coincident with the upper edge of the armour belt, and to this deck also I gave a surfacing of iron, in order to assist in causing any shot that might strike it to glance. The exposed unprotected portions of the ship I at first proposed to fill in solid, so as to render them less combustible; but I suggested that these light exposed upper works might be formed of iron, and thus made entirely incombustible, and this suggestion was approved by the Admiralty Constructors, and adopted by the Board. There are a few other novelties in the vessel—such as the break in the deck to reduce the height of the battery, the protection of the boiler uptake and funnel by the battery, the packed rudder-head and depressed tiller, and numerous modifications of the internal fittings designed to improve ventilation and convenience—but on these I need not dwell. There are, however, two other points which I must not fail to mention, namely, the adoption of an arrangement of transverse ports and short turn-down bulwarks, by which I am enabled, for the first time in naval construction, I believe, to get an almost fore and aft fire from a protected battery with a broadside gun; and, secondly, the method of solidifying the frame by means of dowelled fillings behind the armour. I also gave to the upper timbers an increase of scantling.

Such is a brief summary of the features of the *Enterprise*, by aid of which the Admiralty will, I think I may say, have produced a sea-going ship, plated with $4\frac{1}{2}$-inch armour, with an upper deck nearly 8 feet, and a gunwale nearly 12 feet out of the water; strongly built, well ventilated, with ample accommodation for officers and men; having guns, engines, boilers, funnel, rudder, tiller, steering-wheel, shell room and magazines protected; and fitted with masts and sails which I trust will bear her safely and easily to any corner of the globe in which our rights may need vindication, or our wrongs redress. You will observe, if you have followed me, that notwithstanding all that has been said of the *Enterprise* as a novel and experimental ship (which she unquestionably is) I have really but little claim to credit as a new inventor, and that, in fact, my work has consisted rather in meeting fresh exigencies with known devices than in scheming striking changes, or propounding novel principles. I acknowledge this without the least hesitation—in fact, I state it with some pride—for I think it a better thing by far in these trying times to co-operate, however humbly, in the great and anxious work which the Admiralty have to accomplish, by meeting known wants with simple proposals, than to embarrass, and worry, and denounce, and decry, and agitate against official persons, in the interest of novel, untried, and doubtful schemes.

As regards the other vessels which I am superintending—the *Research* and *Favorite* —they differ from the *Enterprise* in some very important respects. I was fortunately disembarrassed, as regards those vessels, of several limitations that fettered me in the

Enterprise, and being anxious to produce a class of ship of which several might be commenced with confidence, I avoided in them the iron upper works, and have provided for plating them up to the upper deck; so that these two ships, of about 1,250 and 2,180 tons respectively, will be as completely plated with $4\frac{1}{2}$-inch armour as the largest iron-cased ship in existence. Extra strength has been thrown into the bows of all these ships so that they may be strong if used as rams; and you will see that, owing to the concentration of all the principal weights at the centre of the ship, that association of weight with buoyancy which Mr. Scott Russell and Mr. Grantham have so urgently recommended, and those improved steering qualities before mentioned, have been attained in a very unusual degree.

I must now beg you to permit me a few words upon the criticisms which have been passed upon these vessels. The press, (with the exception of one or two weekly journalists who will come round to truth and justice by and bye) have uniformly expressed satisfaction that these vessels have been built. I shall have nothing to say, therefore, by way of reply to any press criticisms. There is, however, one critic upon whose statements I will, if you please, offer a brief observation or two, not on account of any intrinsic merit in his remarks, but because he has printed, and reprinted, and circulated his views so industriously that it is quite possible they may here and there have fallen into the hands of persons who know so little of the subject that they may suppose there is some soundness in them. I allude to the gallant officer, Admiral Halsted. As no officer holding high rank in Her Majesty's Service would be at all likely to take such pains in promulgating what he did not believe to be true, I am desirous, out of regard to that gallant officer as well as to myself, to correct a few of the graver errors into which he has by some means or other fallen. The first inaccuracy which I shall take the liberty of pointing out is that of designating the *Enterprise* as a species of cupola ship. You have heard my description of the vessel, and by what process she was designed, and you will be able to see for yourselves how entirely free she is from both the merits and the demerits peculiar to the cupola plan. In point of fact cupola ships are the only kind of war ships to which the *Enterprise* bears no sort of real resemblance; for between her and ordinary broadside vessels there are comparatively few vital differences. I know, however, how the gallant Admiral got led into his error. It has so happened that owing to the large quantities of bad iron which have been sent in repeatedly for the ship by contractors, and of course, as repeatedly rejected, we have been unable to proceed as rapidly with the ends of the vessel as with the midship portion, which is of timber, and therefore free from difficulty; and the consequence has been that the battery of the ship has been left standing up like a tower, and so as to look to a hasty observer something like a square cupola, if I may imitate Admiral Halsted in the use of such a phrase. Ere long the

ends of the ship will be built up and her appearance so much altered that every one will then wonder what Admiral Halsted could possibly have meant.

I now come, however, to a more remarkable and a more serious error. On the last two pages of his pamphlet the gallant officer gives an elaborate and formal statement concerning different species of iron-cased ships, and that you may judge of the sort of assertions which get circulated at times with an air of accuracy, if not of authority, I will quote from the statement the following words:—"Species 6.—*Enterprise* mode of cupola "ships; as *Enterprise* and *Research*, with hulls about three-fourths unprotected, and built "after an attempt to combine iron topsides upon wooden bottoms." Now as I cannot spend my time day after day in tracking my critics through the mazes of error which they sit industriously, and I think I may say unkindly weaving, I will select this passage, and take issue with the gallant officer upon it, and ask him, not to prove that he is right, but to prove that he is not utterly and egregiously and hopelessly wrong. Admiral Halsted says the *Research* is three-fourths unprotected; the answer is, that the *Research* is as completely protected on the broadside with $4\frac{1}{2}$-inch armour as any ship in the Service, for the armour rises quite up to the upper deck and to the top of the battery. Admiral Halsted says the *Research* is being built after an attempt to combine iron topsides upon wooden bottoms; the *Research* has, however, no iron topsides at all, and was never designed to have any. The *Enterprise* is being built upon that principle, but the Board of Admiralty thought it prudent to get her to sea before they laid down other vessels on the same plan, and to await the experimental solution of the problem. No second vessel of the kind, therefore, was commenced; and, with the strongest desire to be indulgent, I confess myself utterly incapable of conceiving why a gentleman should have rushed into print with a directly contrary statement.

One other point requires attention. It has been a favourite practice with the one or two writers before referred to, to speak disparagingly of the strength of the *Enterprise's* side; and my gallant friend has followed in their track. He and they seem to consider it a great discovery to have found out that the *Enterprise's* side, although covered with $4\frac{1}{2}$-inch plates, will not be quite so strong as the side of the *Warrior*, or as the *Trusty* shield; and they solemnly suggest that the Admiralty should spend a thousand pounds or so on an experiment to ascertain if their view is not correct. I can assure them that the Admiralty will not incur the expense, for they know perfectly well already that the *Enterprise's* side is not fully equal in strength to those structures. Of course we have all along known, and everybody with a grain of common sense must know, that a wooden sloop's side, even when strengthened like the *Enterprise's*, being without an inner iron skin, must be somewhat weaker than the *Warrior's*, which has a stout inner skin. But I should like to ask Admiral Halsted and his allies, whether any sloop's side ever was

made as strong and impregnable as a line-of-battle ship's? And I would ask them further whether they do not consider it would be more fair and reasonable to compare the *Enterprise* with the class of vessel which she is intended to replace—the old wooden sloop, with frames 5 or 6 inches thick only, and with great spaces between them, and with no armour at all—rather than to compare her with the largest iron-cased ship yet afloat—a ship ten times her size?

I confess, sir, that I am somewhat impatient of such criticisms as those to which this little vessel, of less than 1,000 tons, has been subjected by the gallant admiral, who must have subdued the ardour of his gallantry when he turned from his baffled assault upon the *Warrior*, and directed his ponderous artillery against this little craft. She can afford, however, to sustain the attack, for whether penetrable or not by Armstrong or Whitworth shells, she is, I am confident, perfectly proof to the fiercest discharges of the Halsted fire. The simple truth is that the *Enterprise* was never designed to engage large line-of-battle ships, but to perform the duties allotted to our small craft in various parts of the world, which duties have hitherto been performed with unprotected wooden vessels, carrying a few small guns. With her 110-pounder shell guns, and her strengthened frame, and her coating of armour, she *must* be far better fitted for the service than they: and, in addition, although not fully equal in strength to the *Warrior*, she would be capable of engaging with confidence unprotected wooden vessels much larger than herself. It needs no experiment to prove that, as regards her shell-proof qualities, she is quite equal to all this, and more than this was never expected of her by the Board of Admiralty, the Controller of the Navy, or by myself. I almost blush for her opponents when I remember what columns upon columns of their printed criticisms this one simple statement disperses to the winds!

But I must not dwell longer upon such errors. The great doctrine upon which Admiral Halsted insists is, that if the *Enterprise* had been made (what he, by-the-bye, says she is, *viz.*) a cupola ship, she would have been a much better vessel of war than now. He has even recommended that she should be converted into one. I am glad he has gone that length, because every shipbuilder will now see that there really are no bounds to the impracticability of his proposals. He seems to suppose that it would be easy to fit this ship of 990 tons—and with a gunwale 10 or 11 feet from the water—with a cupola large enough to carry two 150-pounders side by side, and to give these guns scope for firing all round the compass, and still to retain her sea-going qualities. I will simply tell him that it cannot be done, and that there is not a naval architect of repute in the world that will undertake to make the conversion for him, although the change would deprive the ship of nearly half her armament.

It seems very desirable, with the remarks of the gallant admiral before us, that we

should enter upon a brief consideration of the difficulties in the way of adopting cupola ships generally for sea-going purposes. I have no prejudices, I may say, against these vessels. I was one of the first, if not the very first, person who asked through the press that a thorough and impartial investigation of the cupola system should be entered upon; I have conversed with Capt. Coles scores of times on the subject; I have been cognizant of most that has been done at the Admiralty in the way of designing such ships; and I have seen cupola ships building in private dockyards. I am still most anxious to ascertain their best capabilities. But there are great difficulties in the way of using the cupola for sea-going purposes, as I will try to explain to you.

Before doing this, however, I may remark that we must drop the notion with which Capt. Coles seems to have started, and which was embodied in the *Trusty* shield. We have no longer to do with cupolas, for he has now adopted turrets, or upright cylinders like the *Monitor's*, which are very different things from sloping shields. They are different, first, because they no longer protect the gunners from vertical fire. The gunners may of course be protected from such fire by covering the turrets over; but this requires special armour for the purpose. The same armour no longer effects both objects. They are different also because they no longer have the advantage so much insisted upon by Admiral Halsted, of glancing the shot off them. Capt. Coles's turrets are now made 25 feet in diameter, and therefore always present square to the enemy a surface, say 10 feet wide and 6 or 7 feet high, in which there is only a single foot of curvature. At short range, and with the modern accuracy of fire, this surface would be struck by every shot, and always be struck square, for in whatever direction the enemy may lie the turret will always present one practically flat side to it. So far from glancing the enemy's shot, therefore, the turret will be much worse off than an ordinary ship's side battery, which can never be struck square except when the enemy lies quite opposite to it.

We must also drop, for the present at any rate, the notion that we can fire more rapidly from a turret than from the broadside. This was done in the *Trusty* because the gun was breech-loading, and ran out of itself. But we are now to carry 300-pounders in turrets, and we have no breech-loading guns of that size, nor are we likely to have; and consequently it would be a pure assumption to suppose that we can fire faster in turrets than out of them. In fact, until we have had actual practice with 300-pounders in 25-feet turrets, we cannot be sure that they can be loaded and fired with anything like the same convenience and rapidity as broadside guns, especially if we take to training broadside guns mechanically.

Further, the change from cupolas to turrets has left us in doubt whether such apparatus will stand the fire of heavy ordnance. The blow of a 300-pounder upon an upright cylinder may have a very different effect to the blow of a 68-pounder, or a

110-pounder, upon a sloping shield. It may hereafter be proved that such a structure will stand such a fire, but at present the matter is in doubt.

Then there is a general objection to staking our naval interests upon turret or cupola ships, which I may mention among these preliminary considerations, because I have never yet heard it answered satisfactorily. I allude to the ease with which the turret, or cupola, may be wedged up, or spiked, so to speak, by boarders. Some naval officers with whom I have conversed, declare that they would not take the trouble to fight such ships, but would range alongside of them, fling a boarding party with long pointed wedges on board to jam the turrets, and tow the whole bodily off. I do not wish to insist unduly on this objection, but I really have seen no demonstration of the impracticability of such a proceeding. I must say, however, that I do not myself despair of remedying this particular defect of the cupola system.

I will pass, however, from this class of considerations to speak more particularly of sea-going shield ships. Now, if a ship is to be fit to go to sea at any time and at all times, you must not give her a deck close down to the water, and nothing above it. In a shield ship you can have no permanent bulwarks above your upper deck, or else you cannot fire all round, which it is the special merit of the shield to do. Your upper deck itself, therefore, must be well up out of the water, and the longer you make the ship, and the higher speed you give her, the higher this deck must be. I should think the deck of no sea-going ship whose bulwarks must turn down in action ought to be less than 5 or 6 feet out of the water; otherwise the sea would wash over, and destroy the health and comfort of the crew. If, then, we assume that the ship is to be plated up to this deck all round, and that the armour is to reach down as usual to, say 4 feet below the water, we at once get a depth of 9 or 10 feet of armour all round the ship, in addition to the armour of the turrets. Here, then, at the very outset, all hope of a *small* sea-going turret ship, wholly armour-plated, to steam at a fair speed, is at once annihilated. If we take a vessel no larger than the *Enterprise*, for example, we at once find that we require about 400 tons of armour and backing (taking $4\frac{1}{2}$-inch iron on 18 inches of teak) on the side only; and if we put into her but a single turret to carry a couple of 300-pounders, we must add, say 120 tons for its weight; so that our armour alone will weigh considerably over 500 tons. Now, I am sorry to say—and no naval architect will contradict me—that we cannot possibly carry this amount of armour on a vessel of the size of the *Enterprise*, and still preserve the buoyant, and steaming, and sailing, and steering qualities which she possesses. Our smallest shield ship, carrying but a single turret, if wholly plated, and made seaworthy, must be considerably larger than that vessel. I have not seen a one-turret sea-going iron-plated ship, but I have seen a two-turret vessel of that kind building in the dockyard of one of our very

foremost private shipbuilders; and I will tell you what she is like. She is, if I remember rightly, about 240 feet long; is of considerably more than *twice* the tonnage of the *Enterprise;* has an upper deck only about 4 or 5 feet from the water, and armour only 3 feet below it; has only 9-inch teak behind $4\frac{1}{2}$-inch armour; has but comparatively little steam power; has no prospect of sailing well; and yet has had that all-round fire which is supposed to be the chief merit of cupola ships sacrificed to a very large extent by the erection of permanent bulwarks forward and aft. In fact, the power of firing either ahead or astern is not possessed by her, for without these permanent bulwarks she would be unsafe at sea; and it remains to be seen whether she will be safe even under this disadvantage.

Admiral Halsted tells us that there is now building on the Clyde a true cupola ship for the Danes, armoured from end to end, carrying two cupolas with two large guns in each, (by implication 110-pounders,) and yet is of but 1,200 tons burden. He forces us also to infer that she is a thoroughly sea-going ship; that her armour is of the usual thickness and extent, and that she will steam and sail fairly. Now, I am not in possession of the particulars of this Danish ship; but I have no hesitation in assuring you that, if Admiral Halsted has not been wholly misinformed, and if a Danish cupola ship of 1,200 tons is now building, she does not, for she cannot, possess all the characteristics here accredited to her. I am sorry she is so far off as the Clyde. I wish marvels of this kind were not always so very far away. I wish they would gather shape and substance on the banks of the Thames, so that we could all adjourn from this place to inspect them. Perhaps Admiral Halsted will be kind enough to give us further information presently concerning this particular wonder, because, if he can prove himself correct on all the points which he has stated and implied, he will convict us shipbuilders of some very mistaken notions. But I am afraid the laws of gravity, the laws of fluid displacement, the laws of fluid resistance—in short, the laws of nature, are against him in the matter. At any rate I cannot help considering him mistaken until I have indubitable proof of his accuracy.

But we shall be told, probably, that Admiral Halsted has the authority of Capt. Coles in support of his views, and I must admit that the latter gallant officer does express very great confidence in the availability of the cupola system for sea-going ships. He has recently published a pamphlet on broadside ships and shield ships, in which he more than once states that the latter are peculiarly adapted for foreign service. There also appeared a month ago only, in a weekly scientific journal, a table which seems to have been furnished by him, and in which it is laid down that a shield ship can be built 285 feet long, 50 broad, of 3,700 tons, carrying eight 300-pounders, (in four shields, I presume) and having a spread of 32,456 feet of canvas, and engines of 800-horse power, giving

a speed of 13 knots; and not only is this account of a shield ship given, but a comparison is drawn between her and Her Majesty's ship *Defence*, very much to the disadvantage of the latter. Now, we are met here as scientific men, to look facts in the face, without fear or favour; and in the exercise of what I feel to be a professional duty, and with a full consciousness of the responsibility which is involved in my statement, I must tell you, and I must tell Capt. Coles, that the representations here put forth cannot be substantiated in practice. No such ship as is described in the publication in question can be built. A ship built of the usual strength, carrying the usual sea stores, of the dimensions given, and steaming at 13 knots an hour, will not carry much more than half the armour and half the guns which have been accredited to her in these published statements. The accomplished naval architects around me will support me, I am sure, in this allegation, because they know perfectly well what is possible and what is not in these matters. It is a cause of great pain to me to have to express thus openly my distrust of the statements and calculations put forth by my gallant friends; but we have public duties to perform, and no good purpose can be served by shrinking from the fullest discussion of a subject which is continually before us in the press and in Parliament. I repeat, that neither Capt. Coles, nor Admiral Halsted, nor you, nor I, nor any one, can produce a ship of the dimensions given that shall be covered all over with $4\frac{1}{2}$-inch armour, carry eight 300-pounders in turrets, and steam at 13 knots an hour.

I must go a step farther, and must request you to allow me to point out that serious mistakes have been made by injudicious comparisons between round shot and rifled shot. In the publications just adverted to, Capt. Coles everywhere gives shield ships the benefit of the great difference between the weights of these two kinds of projectiles. In his comparison of the *Defence* with the ideal shield ship, for example, he makes H.M. ship look ridiculous, by giving her only 560 lbs. as the total weight of a broadside of shot, whereas his own ship has 2,400 lbs. Now, the *Defence* can carry the 110-pounder gun for elongated shot just as well as she can carry the 68-pounder gun for round shot; only the latter is considered the more effective of the two by some persons; and, on the other hand, the 300-pounder Armstrong used last week at Shoeburyness produced, it is everywhere admitted, I believe, almost as great an effect with a round shot weighing 150 lbs. as with a long rifled shot weighing twice as much. The only fair way, then, in my opinion, is to compare round shot with round shot, and rifled with rifled. If we do this in the instance just mentioned, we shall, in the first case, get for the *Defence* 476 lbs., and for the shield ship 1,200; and, in the other case (rifled shot), 770 for the former, and 2,400 for the latter. This, however, is supposing the shield ship to carry eight 300-pounders; but she really can carry no more than four; and the figures then become, *Defence* 476, shield ship, 600, in the first case; and *Defence* 770, shield ship 1,200, in the

second. But this is giving the shield ship all the guns on one side; suppose her now to be engaged on both sides, as such a ship may often be, and we then get *Defence* 476, shield ship 300, in the first case; and *Defence* 770, shield ship 600, in the second case. Here, then, we see that even the *Defence* (which is the least favourable ship that can be chosen for such a comparison out of our whole iron-cased fleet) actually is considerably superior to the shield ship, which at first sight looked so imposing beside her. But if instead of the *Defence* we take the *Valiant*, a ship of precisely the same length, and only 340 tons larger, but plated more completely, the shield ship will find the tables turned still more against her. For, even when we give the shield ship all her guns on one side, the *Valiant* will fire a broadside of round shot of 1,020 lbs. against her 600 lbs., and a broadside of long shot of 1,650 lbs. against her 1,200 lbs. And when we engage each ship on both sides, we find that the *Valiant* will throw a broadside of round shot weighing 1,020 lbs. against hers of 300 lbs. only; and a broadside of long shot weighing 1,650 lbs. against hers of 600 lbs.; that is to say, the *Valiant* will throw about three times as heavy a broadside as the shield ship. Thus we see that *instead of the shield ship being five times as powerful as the broadside ship, as Capt. Coles represents, the broadside ship is three times as powerful as she under such circumstances!* Add to all this the fact that the *Defence*, at least, has now proved herself a splendid sea-going ship, and that we do not yet know whether cupola ships can get to sea at all with security, and we shall have a fairer estimate of the subject than we started with.

There is another subject of great importance concerning which I must venture to say that the statements of my gallant friends Admiral Halsted and Capt. Coles are open to correction. They both assume that a big gun—say a 300-pounder, or, if you please, a 600-pounder—cannot be worked satisfactorily at a broadside port. Now I cannot assent to this. I am at a loss to understand on what grounds the notion is based; and I will make bold to say that such guns can be worked there; and I know that I shall have the cordial support of my gallant friend Capt. Scott, and of numerous other gentlemen in putting forward this view. Suppose the gun to weigh 20 or 30 tons; well, we cannot train it with handspikes I know, but why cannot we move it mechanically about a fixed centre, and upon rails, as easily as a turret weighing with its guns say 150 tons can be moved? I do not wish to draw too largely upon the liberality of the gallant gentlemen in question, but I would ask them to concede to us the power of moving and controlling say one fifth the weight which they can manage so easily. I know that the circumstances of broadside and central guns are not precisely the same, but then if we do without the 120-ton turret we can afford to accept different circumstances. And it may be not amiss to say, in this connection, that as a shipbuilder I would much prefer—I cannot express how much I would prefer—to get rid of these tremendously heavy structures pivoted on

the deck in the middle of a ship that has to be swayed and knocked about in storms at sea. If we place the guns at broadside ports as heretofore, we can incorporate the weight of armour required for these colossal revolving towers in the hull of the ship, and save ourselves all the inconvenience and risk of having them loose during an action on the ocean. I say that every wise man who has to build an iron-cased ship is anxious not only to get these large masses of armour fixed, but also to get them so intimately bound up with the frames and plating that they shall form a portion of the solid hull itself, and assist that hull to withstand the violent jerks and strains to which the angry winds and waves are but too prone to subject it. I think we may undertake to work the guns at the broadside with infinitely greater confidence, than we can undertake to give strength and security to a ship which has masses of metal weighing 150 tons each, pivoted and balanced at different points along the deck, and deprived of the direct support of the frames and plating of the hull. I do not say that even this cannot be done; but I do say, because I must say, that it can only be done by means of a large increase in the weight of the decks and their supports, and that a shipbuilder is bound to consider seriously whether the end to be attained is sufficient to justify the means.

I have already shewn that wholly armour-plated shield ships fit for sea-going service cannot possibly be built of small dimensions. If Capt. Coles and Admiral Halsted will not object to following in the track of the *Enterprise* design and adopt partial plating, they will be able to approach much more nearly to their object. I know it will require some self-denial on their part to do this, because they have drawn so many severe comparisons between our "partially plated" and their "wholly plated" ships, that it will require a good deal of true, self-denying courage to enable them to accept the system so long abjured. Even the latest of their published pamphlets, the "corrected editions," must be ignored by them, because in those pamphlets we never hear a word of imperfectly plated shield ships. They are always *wholly* plated, while the *Warrior*, and *Defence*, and *Valiant*, and *Enterprise* get many a hard knock on their unprotected portions. The word "partially" against the existing ships of the Government, and the word "wholly" against both the real and the imaginary shield ship, are printed in the very first column and the very largest type. But the simple truth is—and my gallant friends must come round to it sooner or later—that if they are to build, I will not say small sea-going ships, but such as are not immoderately large and costly, they must surrender a half of their armour, and begin afresh. It is not I, nor you, nor the Admiralty who insist on this, but those laws of nature which never yield either to the warmest partizan or to the hottest enthusiast. But even if our friends give in on this fundamental point, their difficulties are not, I deeply regret to tell them, at an end. If the ideal shield ship, before discussed, is stripped of half her armour, inexorable science will not yet be satisfied. It demands

half her guns and turrets as well. It is useless to resist her. She will not permit them to carry more than two out of their four turrets, and four out of their eight guns, at thirteen knots an hour, with the size ship they propose. I am sorry for them, especially as their views have been so widely circulated—quoted even in the Imperial Parliament; but I cannot help them, nor can any shipbuilder in the world do more than the laws of nature will allow. If Capt. Coles will only help us out of these difficulties I shall be delighted, for I am most anxious, and so are the Admiralty doubtless, to see his inventions developed as fully, and speedily, and successfully as possible.

I will add but a word or two on those improvements, which I hope to see carried out. First, we must have much thicker armour applied, at least to a few ships, and I am glad to tell you that we know perfectly well how to carry it. We are not, as shipbuilders, by any means daunted yet; on the contrary, we are quite prepared, I assure you, in so far as the science of the profession goes, to send good, fast, seaworthy ships to sea with 6, 8, 10, or even 12-inch armour upon them. There are manufacturing difficulties in the way, but they will be got over. Next, we must have large guns. We must have them not only as superior offensive weapons, but because we can do with fewer of them, and so diminish the extent as we increase the thickness of our plating. And herein we have another of those oft-recurring examples of the manner in which when we seem to be driven by science in the very "teeth of clenched antagonisms" we find our path has really been made easy for us. Who would have thought that the very things, the big guns, which at first sight seemed to give the death-blow to armour-plated ships, would prove to be the very things which make them more and more practicable. But it is so. The bigger the guns the fewer we require, and the fewer the guns the more concentrated may be the plating. Shipbuilders, therefore, want big guns. But then we must work them no longer after the manner of the first savage who prised a log round with a stick or the limb of a tree—for that is the true type of the handspike system of training guns. We must work such guns mechanically—load them mechanically, train them mechanically, run them out mechanically, and this we can very satisfactorily do at broadside ports.

The next things we must have, in our largest ships at any rate, are a high speed, and a larger supply of fuel. Every one is alive to these necessities, and no pains will be spared to secure them. We also want, and shall secure, the invaluable power of turning rapidly. I look with much hope to the double-screw system, and wish I could ascertain on irrefragable evidence that no loss of speed attended it. At present, I am afraid, there is a loss, although there will not be wanting persons who will distinctly assure us of the contrary. If there is no loss of speed, then all other objections to the system may be set aside, for the power of turning in a short compass is of unspeakable

value. Speed and steering-power are the life and soul of a big man-of-war, especially if she has—as she will henceforth have—a bow strengthened to give effect to the desires of the gallant admiral, Sir George Sartorius, and to cleave her foe at a blow upon an emergency. We *must* have abundant turning-power, either by using two screws, or, as Mr. Scott Russell prefers, I believe, by employing very large rudders, and putting steam-power upon the tillers. We may also be able to assist ourselves by partially balancing the rudder. This is not a thing to be done hastily, although it makes the steering wonderfully easy; it requires to be tested in many ways by careful experiment, and a gallant officer, who is distinguished for his scientific attainments, and is an Associate of this Institution, Capt. Astley Cooper Key, R.N., has, with the approval of the Controller of the Navy, been making careful trials of the plan, and will, doubtless, help us greatly to settle the question wisely. We must also improve the safety of our iron ships by further dividing them into water-tight compartments, without further checking their ventilation; and this we may do successfully, I believe, by adopting Mr. Lungley's unsinkable or trunk principle.

I will not detain you by mentioning other improvements which are before us, and will be speedily carried out. I have only thought it just to myself to mention these leading ideas, lest I should be supposed to have my views and desires bound up in the few wooden vessels with which I happened to become first associated. The *Enterprise*, *Research*, and *Favorite*, certainly represent my ideas, in so far as I could give scope to them under the peculiar circumstances of their construction, and I am perfectly willing to be judged by a comparison of those vessels with others of like size. But he would be a very untrustworthy man in these days who committed himself wholly to any one design or kind of ship; and it is now, and will always be my desire and my delight to view with impartiality every new design, and every fresh proposal, as freely as if the *Enterprise* had never existed, subjecting myself solely to those principles of science which at once stimulate us to progress and deter us from error.

DISCUSSION ON THE PRECEDING PAPERS.

Rear-Admiral E. P. Halsted, Assoc. Mem. Council, I.N.A.: I promise to detain the meeting as short a time as possible; but having been so pointedly alluded to by Mr. Reed (whose services as Secretary I am sorry to find we are about to lose), I cannot allow this opportunity to pass without a reply to some of his observations. In the case of the *Research*, I may be allowed to say that she was built at Pembroke. If she had been built within the limits of a reasonable journey, I should have taken the opportunity of making myself personally acquainted with those matters of which I have treated. I had nevertheless a confident belief that the facts respecting the *Research* were as I stated them; and if in error I am grateful for correction. Now, Mr. Reed in his Paper has treated the subject as if I had given up the points which I

brought forward with regard to these ships. I beg to say, that what appears as a note in my pamphlet is applicable to the *Enterprise* if not to the *Research*. He seems to think I have abandoned the question of the protected portion of the battery; but I can assure him I have not done so. There was a statement made in the House of Lords by the First Lord of the Admiralty which has fully borne out the views which I entertain on this subject. I will read to you the extract from the speech of the Duke of Somerset in April, 1862, which is quoted in my pamphlet; it is as follows:—"In April last, the country, through the "House of Lords, was informed on the highest naval authority that the *Warrior* and *Black Prince* of "6,000 tons, carried each but twenty-six protected guns within their iron casings; and that the *Resistance* "and *Defence* of 3,700 tons, carried each but twelve guns similarly protected; the other guns of these "ships not protected within iron casings, such as those removed from the *Achilles*, being expressly "designated thus: '*I do not call these fighting guns like the others.*'" Now if that is not a practical confirmation of the objection I have made to our unprotected batteries I don't know what is. It is here stated that they are not *protected fighting guns.* I say, relieve us of all guns that are not fighting guns! It is the same as if an officer in command of troops on shore had three hundred men out of a regiment *non-fighting men*, for the case is similar as regards fourteen out of the forty guns of the *Warrior* and *Black Prince;* and what would be the position of a regiment of troops under circumstances of attack if one third of the number were non-fighting men? All I can say is I think our friends on shore would find themselves in a position against which they would revolt; and I revolt against it as applied to non-fighting guns. In other respects as regards my pamphlet, I believe no person who has been to Deptford and seen the large square fighting box of the *Enterprise*, having a length of 30 feet in a ship 180 feet long, extending nearly across the entire breadth of the ship, and found himself enclosed in that square box with four guns—two on each broadside—I say, I do not think any person could in that position, have fancied himself in other than a cupola ship. She is a modification of a cupola, square instead of round, fixed instead of revolving, and working the guns upon the broadside instead of upon the central system. The whole of my pamphlet to which exception is taken merely carries out comparison between the two forms of cupola—the one invented by Capt. Coles, and the other (as I believe in the case of the *Enterprise*), an imitation of it. I will not say more with regard to that part of the charge, but simply repeat that naval officers, liable to be called upon to take these ships into action and fight with them, have a right to regard them as fighting weapons with which they can or cannot fulfil the duty of capturing or destroying an enemy.

The whole of my pamphlet goes to the point of requiring that this new mode of cupola ship shall be subjected to the same proof before it is sent into action that others have been subjected to, and which has been the case with our armour ships generally. If the *Minotaur* target had been fired at before that vessel was built, no doubt she and her two sister ships would not have been in their present position. I believe it would be the same with the *Warrior*, if the two parts—the thick and the thin—of that vessel had been put to proof. Moreover, if the representation of the true target of the *Royal Oak* and others of her class which are to be built were put down and fired at at Shoeburyness as that of the *Warrior* was, I believe there would not be a question as to the mode in which the five new ships should be constructed. I have simply advocated the doing of the same thing in the new style of cupola ships now being built. Whoever is the inventor, I look upon it as the weapon which is put into our hands to fight with. It is, therefore, natural that we should look at its qualifications for that purpose, and I limit those qualifications to the powers of offence and defence. I am sorry to hear therefore from Mr. Reed, that it will not be put to that

proof. All I can say is, I again urge upon him to do so. I stand upon the broad ground on which I propose to exercise my professional judgment as a naval officer liable to receive these vessels as weapons of war to fight with, whether or not I am likely to succeed with them.

I now pass to the subjects more immediately treated in the Paper read by Mr. Fairbairn. He has based his statements upon the assumption that the 300-pounder gun used against the *Warrior* target in April last had put its shot through the target. He is, of course, not responsible for having made that mistake. The statement had been made throughout the country. But I have a drawing taken by a most competent person, shewing what really happened. This is the only experiment made upon the *Warrior* target last year with the 300-pounder gun. It was not, in fact, a 300-lb. shot, as the gun had not been rifled. I believe the weight of the shot was 156 lbs., fired from a smooth bore; and the first two shots hit tolerably close together. They were fired at a part of the target which was not sound, it having received twelve shots in the previous October. These two shots were fired with 40-lb. charges, neither shot passed into the ship. Upon thrusting the hand into the hole, it was found that the shot was in fragments. The skin, however, was burst so as to enable the fragments of the shot and armour plate to pass through. The charge was increased from 40 lbs. to 50 lbs., and the sound plates were fired at. The first shot, however, entered only 8½ inches, where it became embedded. The second shot was embedded in the backing at a depth of 10 inches, and it was with regard to this latter shot that the country rang, that it had gone through and through the ship. This error was afterwards corrected in the House of Commons by Lord Clarence Paget. The third shot was fired on the 20th of May, I believe upon Mr. Samuda's target, the Duke of Somerset having requested that another shot should be fired under the same circumstances as before. That entered only 10 inches (I am speaking of the rear of the shot). This brings me to another question in which Mr. Scott Russell speaks of the performances of a real 300-pounder gun—that is, as it is in existence now, which is precisely similar to the gun in question in construction, weight, and calibre. It is a *real* 300-pounder, inasmuch as it was rifled without being tried as a *smooth bore*, and carries 300-lb. shot, as the other gun would have done had it been rifled. Mr. Scott Russell calculates upon the necessity of an 8-inch plate to give sufficient resistance. We now see plainly when this same gun has an increased weight of shot given to it, *viz.*, 300 lbs. instead of 150 lbs., which was the case the other day, and with this increase of weight a decrease of charge from 50 lbs. to 45 lbs., that we have no right to suppose the power of that gun could be greater than if it had been used again as a smooth bore; and therefore, if we were to re-erect the *Warrior* target as it was when fired at with a smooth-bore gun, in my opinion our judgment beforehand would be, that it would not have received so much damage.

Mr. Scott Russell: With the same charge the lighter shot has always been found to produce the greater effect.

Rear-Admiral Halsted: The *Warrior* target would better have resisted the 300-lb. shot of this year than it did that of 156 lbs. last year; and it would seem that upon that Mr. Scott Russell has formed his calculation that a 4½-inch plate will resist a 68-lb. shot. In company with Capt. Hewlett I witnessed the experiments at Portsmouth upon the sides of the *Sultan* with 4½-inch plates. It was a great effort with a 68-pounder to put a shot into that vessel. Capt. Hewlett raised the charge for the 68-pounder from 16 lbs. to 22 lbs. and even 25 lbs. of powder. He used carefully-selected shot of wrought iron as well as cast iron and brought the gun up to within 50 yards of the plates. In each case the shots penetrated the armour

plates, but in each case they stuck in the side of the ship; and the amount of penetration of the wrought iron shot, as compared with the cast iron, was carefully noted. But I put this question to Capt. Hewlett,—"What was the amount of splinter inside the ship?" He replied, "None." I then asked him, "Do you "consider people would have been as safe inside that ship as we are inside this carriage?" He replied, "Yes, decidedly." The 68-lb. shot had not power to force through the side of the *Sultan*—an old ship, with a timber backing of only 22 inches thickness. Therefore, I regard the 68-pounder as being completely out of court.

Mr. Scott Russell: In other words 4½-inch plates are more than shot-proof against the 68-pounder.

Admiral Halsted: It certainly would not have gone inside the ship, nor have done any real harm. The hole made by the shot was perfectly round; and if covered with hot pitch or putty no one would have known that any harm had been done.

As to Mr. Fairbairn's remarks upon the Whitworth gun, there is no doubt whatever in my mind that the firing of the Whitworth gun in November last has initiated an absolute revolution with regard to the effects of artillery upon armour-coated ships; and that henceforth the resistance of armour ships will have to be measured neither by shot nor shell. Wonderful though it may seem the penetration of the shell is greater than that of the solid shot. It is a better projectile against iron than solid shot can be made to be; and I account for this in a great degree thus: there is a difficulty in giving the necessary temper throughout the whole mass of the solid shot, and it either gets distorted or broken to pieces, either result being the loss of so much power to the penetrating force. If the plate breaks the shot, the amount of force which breaks it is so much taken from its power to break the plate; but inasmuch as the shell is hollow, Mr. Whitworth has been able to get at the interior portion to give it equal temper of metal throughout so as to enable it without alteration of its form to do that which the solid shot cannot do. Of course I am now speaking of dead shells. Mr. Whitworth tempers his shells in such a way that they may be picked up and fired again.

Mr. Samuda: Where have you seen that done?

Admiral Halsted: Sir John Hay could show you plenty of them from the experiments of the Iron Plate Committee.

Mr. Samuda: I have seen the shells fired, but never the same shell used twice.

Admiral Halsted: It has been done repeatedly with the 12-lb. shells. Mr. Whitworth is now producing guns to fire shells with a charge of 40 lbs. of powder. In support of the view which Mr. Whitworth has brought forward by the introduction of these shells, I will just read you an extract from the Report of the Ordnance Select Committee with regard to these very experiments. It is as follows:—"It must be remarked also that these projectiles, though flat-ended, were fired with great accuracy, and "were much truer in their flight than any flat-ended projectile which the committee had hitherto seen "fired. The results recorded were obtained partly by using a heavier charge of powder in proportion to "the weight of the projectile than had hitherto been used in any rifled ordnance. But the great merit due "to Mr. Whitworth on this occasion seems to be in the successful manufacture of a metal possessing such "hardness and temper as to be capable of penetrating wrought-iron plates; yet, at the same time, so tough "as not to crush or break on striking the target. On no previous occasion have the committee seen a shell "of any description penetrate more than one inch of iron without breaking up on impact."

I hold in my hand a drawing made after the target was taken to pieces, of the effects produced by

these shells. It not only shows the force of the explosion through the target, but also what would have taken place if there had not been an inner skin of iron to control the interior force of the explosion.

Captain Cowper Coles, R.N., Assoc. I.N.A.: I will not detain the meeting a minute, for to-morrow I have to read a Paper upon my principle of sea-going ships, which will develope my plan. All I want to say is this: I see my Paper is last upon the list for to-morrow morning, and I hope that time will be allowed me to read it. I merely wish to put forward my plan of cupola vessel as carrying a greater amount of broadside for tonnage than an ordinary broadside ship. I certainly was not prepared for the broadside I have received this morning from Mr. Reed; but it will be open to discuss how far I am wrong in my calculations.

The Right Hon. President: I would say one word in consequence of what has just fallen from Capt. Coles. We must all feel that in the Paper read by Mr. Reed, the great ability of which must have struck every one who heard it, some very strong criticisms were passed upon Capt. Coles's plan. I would therefore submit to the meeting whether it would not be fair, as between man and man, that Capt. Coles should be allowed to read his Paper, which must be regarded very much as a reply to what we have heard to-day, at the commencement of the proceedings to-morrow morning; and I would also suggest, if it can possibly be arranged, with justice to those other gentlemen who have prepared Papers of great interest, that there should be a discussion for a limited period of time upon the subject which these Papers have opened before us. [These suggestions of the President were ultimately agreed to.]

Mr. C. W. Lancaster, Assoc. I.N.A.: I cannot help feeling that it is very important that the discussion on these Papers should not be closed without notice of the table supplied by Professor Pole, and referred to by other gentlemen, in relation to the weight of projectile deemed necessary for the penetration of iron plates. This table, it will be perceived, contains no reference to the diameter of the projectile, which is a matter of the greatest importance, because the law which governs the penetration of masses of iron, has express and particular bearing on this point.

It is well understood by those engaged in the manufacture of iron, that the diameter of the punch must always be in excess of the thickness of the metal to be punched. If this condition be disregarded, the punch will be destroyed instead of the perforation of the metal being accomplished.

Now, it is obvious that any number of pounds, say 500 pounds weight, of projectile may be of any denomination in reference to its diameter. It is simply so much *plus* elongation of the projectile to render it equivalent to any desired weight; but in practice the extremely elongated projectile, be the material what it may, when fired from cannon against iron plates, must present some portion at a tangent to the point of impact, thus rendering the destruction of the projectile itself easy and certain.

The effects of the Whitworth projectile have been very ably described by Admiral Halsted. It is a matter of regret that he did not also refer to the destruction effected in the Warrior target by the 13-inch wrought-iron gun of the Mersey Iron Company. Having been present at the majority of those trials, I feel no hesitation in expressing an opinion, that the destructive effects of that gun were far greater than those of any other gun tried at Shoeburyness The weight of the cast-iron round shot was 284 lbs., charge of powder 74 lbs., and the perforation made by one shot was a parallelogram 2 feet 3 inches by 2 feet, shewing the advantage of the large punching surface of the projectile.

But in viewing this question, too much importance has been attributed to the efforts in this country of private individuals and our Government; and too little notice taken of the efforts of foreign artillerists.

The Americans have made extensive and very successful efforts in reference to the question of artillery *versus* iron-plated ships. Authentic information has been received from my friends in America in reference to experiments conducted in the Washington Navy Yard, from which it appears that with the 15-inch gun now in use in the American Naval Service, targets composed of live oak 6 feet thick, and covered with iron 9 inches thick, have been completely destroyed at a distance of 500 yards.

It may not be without interest to point out that with their accustomed ingenuity, our American cousins have devised a method peculiar in itself, of loading these guns. The gun is placed in the well-known Erricson turret; and the loaders and means of loading are in a much smaller tower placed abaft the gun tower, and amidships. After the gun is fired, the turret is made to revolve until the muzzle of the gun and the loading hole in the smaller turret are coincident: the charges are then inserted and rammed home with great facility. The shot is conducted to the muzzle of the gun along a little tramway.

I will close my remarks by calling attention to the experiments conducted by the French Government, with steel hollow-faced projectiles fired from the French rifled gun with 11 kils. of powder. These steel shot penetrated at 600 metres, 6 inches of iron and 1 metre of wood. It will thus be seen that, however great our own exertions may have been, our foreign competitors are not behind us in the race.

ON THE STEERING OF SHIPS.*

By N. Barnaby, Esq., M.I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 26th, 1863; J. Scott Russell, Esq., F.R.S., Vice-President, in the Chair.]

The subject which is entrusted to me this evening is so important, that while I should wish to see it in abler hands, I think no further time ought be lost in bringing it under discussion. Here the shipbuilder, the engineer, and the sailor meet and take counsel together in matters of common interest. We have very much to learn from each other, and none of us can safely go on alone. My object to-night is not to instruct you, but to direct your thoughts to the consideration of a subject which becomes of greater importance every day.

Within the last twelve months, the idea of employing the momentum of a ship of war as a means of injuring an enemy has gained ground, and nearly all the war ships in course of construction in England and France have such a form of stem, and such increased strength of bow, as to allow them to be used as rams, should the occasion present itself. The *Resistance* and *Defence*, for example, have been shorn of those graceful appendages, the figure-head and knee; the stem has been made to fall back at the head; the bow has been built with extraordinary strength; and various other measures have been taken to make it possible to employ these ships as rams. But it would be idle to suppose that this vast power of attack would be available with their present steerage power. Let us see how the matter stands. Under favourable circumstances, the *Resistance* can turn completely round in six minutes and a half; but in doing this at full speed, *i. e.*, when the time of turning is shortest, she describes a circle 1,800 feet in diameter. Her rudder will not turn her without steerage way, and that steerage way involves the awkward consequence, that if the officer in command wished to turn the ship at full speed through an angle of 90°, in order to bring her stem to bear upon an adversary with whom he had just exchanged broadsides, he would

* Received March 26th, 1863.

find himself at the completion of the operation a quarter of a mile from the place where he commenced it. I do not take this ship in order to exaggerate the difficulty, but because she has been remarkably successful, and is the perfection of our present system of steering. The *Warrior* and *Black Prince* afford a still more striking illustration because of their great weight and length. In the former ship, the time occupied in turning completely round at five different trials varied between 7′ 46″ and 9′ 5″, and averaged 8′ 20″. In the *Black Prince*, the time at six different trials varied between 8′ 3″ and 13′ 33″, and averaged 10′ 22″.

The space traversed by them in turning is so great, that in passing through 90° under the circumstances before mentioned, the vessel would have to travel nearly half a mile. In some circumstances, the only way in which the stem of one of these ships could be brought to bear upon an adversary with which she had exchanged broadsides, and which was lying motionless, would be by performing part of the operation while backing astern, and the rest while advancing; but in performing this manœuvre still more space would have to be traversed, and more time occupied.

In these ships also the ordinary means of steering are as perfect as they can be made. In the *Black Prince* especially, no pains have been spared to perfect the steering gear, and as some naval officers were of opinion that the rudder was too small, its area has been increased from 151 to 178 square feet. But the *Warrior*, which has not been altered, remains superior to her, as has been already shewn. We cannot suppose that any vessel, which was not completely helpless, would suffer herself to be run into by such ships.

What are we doing to remedy this most undesirable condition of things? One cannot deny that there has been considerable activity of invention with regard to steering, but there seems to be much misapprehension on the part of inventors as to what is really needed. An inspection of the models representing improvements in steering, which were sent to the International Exhibition last year, was sufficient to shew this. The majority of them related to improvements in the mode of applying manual power to the ordinary rudder, although the advocates of auxiliary rudders, bow rudders, and balanced rudders were not unrepresented; and there were prominent models of double or steering propellers. No advantage of any consequence is to be expected from the first and most numerous class.

The only real difficulty to be contended against, inside the ship, is friction. Neglecting this, no possible alteration in wheel, or tiller, or yoke, can reduce the labour of the men, without increasing the time occupied in putting the rudder over. Nor, on the other hand, can this time be diminished without increasing the labour of the men.

We already know how to reduce this friction to a small amount, and should gain

very little if we could get rid of it altogether. Inventors in this direction, are more likely to excite ridicule, than to achieve success. There are inventions, it is true, for performing the work of turning the rudder by hydraulic or steam power, but supposing such apparatus could be perfected, the condition of things already pointed out in the *Warrior*, *Black Prince*, *Resistance*, and other iron-cased ships, as to the time occupied in turning, would remain. We must therefore look for improvement in the instrument which acts directly upon the water.

Let us consider, first, the size and shape of the *ordinary* rudder. Some gentlemen have very strong opinions on this matter. One eminent shipbuilding firm considers that the lower part of the rudder is of little service, and the rudders made by that firm are accordingly lean at the bottom. Others are of opinion that no rudder can be good unless it is very broad at the bottom; and there are some staunch advocates for a great breadth at the height of the centre of pressure. And then, as to size, it has been asserted by eminent naval officers that the rudders of modern men-of-war are too small, and that the sluggishness of the *Warrior* in answering her helm is due to that cause.

Now, an important point which has to be considered in regard to these matters, is this:—Is the rudder large enough to absorb, and to absorb economically, all the power we can put on it? If we find, as we do in nearly all our screw ships, that the men at the wheel cannot hold the rudder at the extreme angle for which it is bearded, but have to exert all their force, when the vessel is at full speed, in order to hold the helm at 15° or 16°, then we may be sure that the area of the rudder does not require to be increased. There are, in fact, certain considerations which shew, that as a general rule, our rudders are *too large*.

It will be seen that the further the rudder is put over, the greater is the velocity of the fluid in a direction perpendicular to its surface, or the *effective* velocity of the fluid. There is therefore an *advantage, so far as increase of pressure is concerned*, in working with a large angle, or with a small rudder, see Fig. 1, Plate II.* But, on the other hand, the effect of the pressure on the rudder in turning the ship, depends on the leverage, or, on the moment of the pressure about the centre of gravity of the ship, which is in proportion to the length of the perpendicular drawn from the centre of gravity, upon the direction of the resultant pressure. The length of this line diminishes as the angle increases, so that, *so far as the leverage is concerned*, there is a *disadvantage* in large angles and small rudders. A third consideration, pointing to the same conclusion as the second, is, that large angles, or small rudders require more time in putting the rudder over, so that the vessel would not answer her helm so readily with

* If the length of the longer arrow in the figure represent the velocity of the fluid in the direction of the ship's course, then the length of the shorter arrow will represent the velocity perpendicular to the surface of the rudder.

a small rudder as with a large one. And then, there is a fourth consideration to which my attention has been recently directed by Mr. Barnes, of the Department of the Controller of the Navy, and one of the Members of this Institution, which has, I think, hitherto escaped attention, *viz.* :—That while the outer half of the ordinary rudder does no more in turning the ship than the inner half, it absorbs three times the amount of labour on account of its distance from the fulcrum. This is another advantage on the side of the small rudder, and one of considerable consequence. He concludes from it, that rudders which cannot be worked at large angles are not economical, and should be reduced in area until they can be so worked.

If a problem of *maxima* and *minima* be constructed, expressive only of the first two conditions here laid down, it appears that the rudder would be most effective in turning the ship if it were over at an angle of $54\frac{3}{4}°$; but if the fourth or economical consideration be also brought in as one of the conditions of the problem, so as to discover with what angle and breadth of rudder *a given power* on the wheel may operate most effectively on the ship, the angle comes out 45°, and, of course, the breadth of rudder such that the power will just maintain that angle. Although this undoubtedly shews that rudders which can only be worked at 15° or 16° are too large, yet I am afraid that the necessities of a ship which must be sometimes under sail and sometimes under steam will limit improvement in the ordinary rudder in this respect; for a rudder which could be held hard over when under steam, would certainly be too small when under sail.

An improvement has been sought to be made in the ordinary rudder by Mr. Lumley. According to his plan, the after-part or tail of the ordinary rudder is cut off from the fore-part in a vertical straight line. The separated portions are then hinged together, so that there are two sets of hinges, one connecting the entire rudder to the stern-post, and the other connecting the two parts of the rudder.

The object of Mr. Lumley is to cause the after-part to turn round in obedience to the helm, through a greater angle than that made by the foremost portion and by the tiller. Thus the two parts of the rudder which are in one line when the helm is amidships, would make an angle with each other when the helm was put over. This is effected by attaching on each side of the tail of the rudder, and at about half way down, a chain which passes through a hole in the foremost piece of rudder and is shackled to the stern-post. When the helm is put over, the chain *from* which the rudder is turning, being shackled at a little distance from the centre of the pintles (half the thickness of the stern-post), will not permit the tail of the rudder to describe an exact circle about the centre of the pintles, but, restricting its motions, compels it to move through a small angle about the joint between the two portions of the rudder. Trials of this rudder have been made in the *Bullfinch* gunboat, and in the *Columbine*, a vessel of 669 tons,

and 150-horse power. On comparing the results of the trials with those obtained from the ordinary rudders of these vessels, it appears that Mr. Lumley has the advantage. In the larger vessel the time occupied in turning was, with the helm hard over, nearly the same in both cases. Where the helm was over only 10° or 11°, Mr. Lumley gained a few seconds in completing the circle from rest, and as much as two minutes in turning at full speed. In all these cases it will be apparent that most work had been done in turning by Mr. Lumley's rudder, as a portion of it was always forced over to a greater angle than the helm. The advantage gained by him in reducing the space over which the vessel has to travel during the operation of turning, appears to have been more decided. While there are certain very evident objections which may be urged against this form of rudder, it has obtained a greater success than might have been expected.

Recent experiments have also been made in a gunboat with what is called the balanced rudder. This description of rudder has the important advantage, that the rudder surface and the steering power may be increased without requiring any increase in the power applied. This idea is so promising that it has been often patented. As long ago as 1790 a patent was granted to Charles, Earl Stanhope, for this invention, called by him an equipollent rudder. It has been adopted also in some of Mr. Scott Russell's ships, and I believe in others; but, so far as I can learn, these rudders, when used in *screw vessels*, have always been placed *before* the screw.

In the experiments with the balanced rudder to which I have just referred, made by Capt. Key, R.N., the rudder was fitted in a temporary manner *abaft* the screw, and the following facts were established:—

1.—That with a very small exertion of power the rudder may be put over to any angle when the vessel is at full speed:

2.—That in order to obtain the necessary balance for this purpose, with these relative positions of rudder and screw, the after part of the rudder must be *twice* as large as the fore part:

3.—That whereas the ordinary rudder can only be got over to 15° or 16° when the ship is at full speed, and that with great effort, this rudder can be held with ease at angles up to 45°, and that by thus increasing the angle, both the diameter of the circle and the time of turning are slightly diminished:

4.—That an *increase* in the *area* of the rudder, while it reduced the diameter of the circle described, and also the time of describing the first quadrant of the circle, increased the whole time of describing the circle; and

5.—That with the same area and angle of rudder, an *increase* in the *speed* of the vessel shortened the time of describing the circle, while it increased the diameter of the circle described.

As has been stated, the advantage over the ordinary rudder with regard to quickness of turning, and turning space required, was slight. This was probably owing, to some extent, to the fact that the balanced rudder was further from the screw than the ordinary rudder, and, therefore, did not receive so much assistance from its action upon the water.

It is not however in gunboats, but in ships 300 and 400 feet long that the advantages promised by the balanced rudder are wanted. We are told, for example, that the *Black Prince* was on one occasion turned completely round in 8′ 33″, the rudder being over to 28°; but in order to hold it there it required ten men at the wheel, and thirty men at relieving tackles, no less than forty men being employed at this operation. This is, of course, an extreme case, but it serves to shew that an invention which promises to reduce the number of men required to one or two, has great claims to consideration. An advantage which is of slight consequence in small vessels, assumes in these large vessels very great importance.

But suppose it was considered proved that the balanced rudder would give the advantages desired, where is it to be placed? We are told it must not be before the screw, for in that position it has been found to fail. If placed abaft the stern-post, it is subject to the disadvantage of being too far from the propeller; of suffering from the obstruction interposed by the stern-post; of liability to jam by confining loose ropes, or other partially sunken matter, between the fore edge of the rudder and the back of the post; and, lastly, it requires too great an extension of the stern of the ship.

The question to be considered is, I think, this,—may we not in our large iron ships get rid of the stern-post altogether and place the balanced rudder abaft the propeller, as I have shewn in Fig. 2? In the case of the *Northumberland*, for example, the after stern-post is a mass of iron weighing nine or ten tons. Its only conceivable uses in this ship are to support the rudder, and hold up the stern. I should not have troubled you to consider the latter of these two uses, if I had not heard it strongly insisted upon by some shipbuilders. I must confess myself at a loss to conceive of what service it can be in this respect. If there were any tendency in the stern of the ship to settle down, can it be supposed possible that the long, and comparatively thin forging, which extends from the bottom of this post to the body of the ship, would be so rigid as to refuse to bend two or three inches in ten or eleven feet when this large weight came upon its extreme end? To expect the rudder-post to prevent any *lateral motion* of the stern would be still less reasonable. So far then as the strength of the stern of the ship is concerned, may we not remove the rudder-post in such a ship as the *Northumberland*, *i. e.*, in a ship built of iron, and having no after bearings for the screw?

But, further, is it necessary for the support of the rudder? First, it will be evident

from what has been already said, that although the rudder is supported directly by the stern-post, to which it is hung, yet that indirectly the stern of the ship has to hold both. If instead of attaching the head of the stern-post to the stern of the ship, and hanging the rudder to the post, the rudder were taken hold of by the stern, and the post were removed, does it not appear that the stern would be actually relieved? If the weight of the rudder were thus taken upon one of the decks, it would be possible to make a considerable reduction in the ordinary friction of turning on the braces. A socket in the end of the keel for confining the heel of the rudder would then complete the arrangement.

Before passing from improvements in rudders as a means of obtaining greater steering power, I had intended to consider the value of additional or side rudders, and bow rudders. I will not, however, take up your time on these points further than to say that recent trials have been made in the *Cordelia*, sloop-of-war, of an additional rudder, known as Mulley's auxiliary and reserve rudder. This rudder, which was hinged to the bottom of the ship just before the screw, had an area of $43\frac{1}{2}$ square feet, and was capable of being put over to an angle of 38° with the ship's side.

On making the trials it was found, to the great surprise of the inventor, who had fitted the rudder at his own expense, that the vessel went round faster when the ordinary rudder was acting alone, than she did when the auxiliary was assisting it to the utmost extent of its power. And further, that when the helm of the auxiliary rudder was placed in the opposite direction to that of the ordinary rudder, the ship went round faster than when under the influence of the ordinary rudder alone. The vessel, in fact, always tended strongly to go in the direction opposite to that in which Mr. Mulley intended to put her.

I am afraid we shall find that bow rudders are not much more useful than those proposed by Mr. Mulley, except in vessels designed for running in both directions. When a vessel is going ahead, a bow rudder acts upon water moving much slower than that driven from the screw against the after rudder, and is therefore much less useful. At the same time it would be very difficult to work a bow and stern rudder together in a large ship. Trials are in course of being made upon bow rudders, and we shall perhaps know before long just how matters stand with them.

We must now come to the question of the employment of special machinery for turning the ship, and consider first the use of double screws. The use of two screw-propellers, as illustrated in Figs. 3 and 4 (Fig. 3 being a profile drawing of a section of a proposed vessel whose indicated horse-power of engines is 2,500, and diameter of screw 17 feet, and Fig. 4 a plan drawing of the same section), has been recently brought very

prominently under public notice, although it is not by any means a new invention. The use has, however, been confined to vessels of shallow draught, and in which the diameter of the screw was necessarily small: in the vessels which have been recently built by Messrs. Dudgeon this was the object in view.

From information with which those gentlemen have been kind enough to furnish me, I find that the *Flora*, in which the first of the recent experiments was made, was designed for the *Chinese* coasting trade, on which account it was desirable to carry a large cargo upon a light draught of water. I believe she has not yet reached China, but has been occupied in running in and out of Charleston, a somewhat hazardous service, but one which she has performed successfully.

This vessel is 400 tons builders' measurement, and has engines of 120-horse power. At her trial she reached a speed over 13 knots, and was found to be capable of being turned completely round in her own length in about three and a half minutes.

I am informed that her behaviour at sea has been most satisfactory. That she made the run from Plymouth to Madeira in six days, during which period one pair of engines was stopped for three hours while some adjustment was made, the other in the meantime propelling the vessel without impairing the steering power. After this she was steamed for four days with one engine and one boiler, the other engine being allowed to move without steam. Under these circumstances she made an average speed of $7\frac{1}{2}$ knots, and was found to steer well.

The *Kate*, a somewhat larger vessel than the *Flora*, has been fitted in a similar manner. Her dimensions are as follows:—

		Ft.	In.
Length on load water-line		165	0
Breadth (extreme)		22	6
Depth		13	6
Draught of water	Fore	5	4
	Aft	7	2
Builders' Tonnage	450		

She has separate and independent engines of 60-horse power each, working up to five times the nominal power. There are two three-bladed screws, each of 7 feet in diameter, and 14 feet 6 inches pitch. As they are 9 feet 6 inches apart from centre to centre, there is a clear space of 2 feet between them. A portion of the screw blades, about 9 inches, was exposed above the surface of the water.

Under these circumstances the vessel was tried on the 28th of last month; and from the results of that trial we learn the following facts:—

1.—That with both screws working ahead there is no loss of steering power, compared with ordinary vessels, the circle being completed in 3′ 48″:

2.—That when one screw was stopped, the time of turning under the action of the other screw and the rudder was a little greater, *viz.:* 3′ 58″, but the diameter of the circle in which the vessel turned was about one-third less than before:

3.—That with one of the engines reversed, both engines being driven at full speed, and the rudder hard over, the time of turning was still greater, *viz.:* 4′ 16″, but the vessel turned upon her own centre:

4.—That the vessel could be turned on her own centre by the screws alone, the helm being amidships; but the time occupied in turning was 6′ 55″; and

5.—That the vessel was under perfect command both when steering astern and when steering ahead.

The first thing observable here is, that when the screws are used to assist in steering, the vessel turns more slowly than when under the influence of the rudder alone. This arises to some extent from the fact that the screw which is stopped or reversed, is on the side towards which the rudder is turned, so that the rudder is rendered partially ineffective.

It must also be borne in mind, that this vessel is narrow in proportion to her length; the screws are therefore very close together, and their leverage in turning the vessel small. On this account, I think we might expect a better result in a broader vessel where the screws had a greater leverage. The real gain in this arrangement is, however, the reduction of the space passed over in turning. Our longest vessels may, by these means, be made to turn on their own centres when employing the full power of their engines, instead of making a circuit of nearly two miles.

I think one of the questions we have to discuss is this,—Supposing there is a loss of time in completing a circle by the aid of the double screw, and a little loss of speed, as there will be, is the advantage of being able to turn in that circle without being compelled to move ahead, sufficient to render its adoption in large ships of war expedient? This is a question which I do not feel competent to decide, and upon which some light may perhaps be thrown by naval gentlemen present.

We may confine our attention in this matter to armour-cased ships, either partially or completely protected, as I think we may take it for granted that for the future no large ship of war will be built without such protection. In ships iron-cased the power of rapid manœuvring under the fire of guns will perhaps be of less consequence than in uncased ships, and it is in their aspects as rams that the question will have to be considered.

If we imagine an encounter between the *Black Prince* and *Warrior*, and suppose that one of these ships had been fitted with two screws, and the other had not, we may perhaps be able to estimate the advantages which the two screws would be likely to

give. Would not the power of being able to turn round on a pivot before advancing to strike, or while parrying a blow, give to one of them a great superiority over her adversary? And if the balanced rudder were employed in conjunction with the two screws, we might expect to have not only the advantages of that rudder, which have been already pointed out, but also an improvement in the action of the double screws. We have seen that when one of the screws is stopped, or reversed, the action of the water upon the ordinary rudder is impeded; but with a balanced rudder under these circumstances, the foremost half of the rudder would be receiving the full *impulse of the driving screw.*

We must not conceal from ourselves the fact, that so far as our experiments have gone at present, we have found no means by which we can quicken the rate of turning these large ships. Improvement in this respect has still to be sought. If we adopt both the double screw and the balanced rudder, we have no reason to suppose that our largest ships can be turned completely round in less than seven or eight minutes.

The actual velocity with which the head of the ship moves round in obedience to the helm, *i.e.*, the velocity of the extremities of the ship in a direction at right angles to the length of the ship, I find to be as follows:—

	Length of Ship.	Knots per Hour.
Warrior	380 feet	1·3
Resistance	280 „	1·3
Emerald	237 „	1·1
Liffey	235 „	1·1
Edgar	230 „	0·9
Racoon	200 „	1·2
Kate (most favourable)	165 „	1·5
Kate, when turning with screws and rudder together	165 „	1·3
Columbine, with Mr. Lumley's rudder	160 „	1·2
Bullfinch (gunboat)	106 „	1·5

I can imagine no way of increasing this speed except by the introduction of special machinery for turning. I think, however, you will admit that there is much room for improvement before resorting to that expedient, although the vast importance of an advantage in this respect may before long drive us to its adoption.

I have shewn in Fig. 5, a mode by which this might be effected. I find that a screw only 10 feet in diameter, placed in the bow of the ship, and driven at the speed of nine knots per hour, would perform the same work in turning the *Resistance*, as her rudder would perform when placed at an angle of $24\frac{1}{2}°$, and acted upon by the water driven from the screw at 18 miles per hour. If such a screw were connected with a small engine on the deck, or in the fore hold, there would be no difficulty in driving it at twice the

speed named above; and by these means we might hope to obtain both the advantages we seek, *viz.*, *increased speed in turning*, and *the means of turning on a pivot from rest.*

The disadvantages attending the adoption of such a plan lie upon the surface; but it cannot be doubted that it would give more complete command over the movements of the vessel than that promised by the double screws; while it could be used under sail as well as under steam. I am aware that manœuvring screws have been before proposed. I saw one fitted under Foulerton's patent in the deadwood of the *St. Lawrence* sailing frigate (formerly the renowned *Shannon*), but that screw was very small and was driven by hand, and it would be idle to base any conclusions upon the results obtained from it.

In whatever manner future naval engagements may be conducted, the result of those engagements must largely depend upon the course which is now taken in providing machinery for steering. But in view of contests between ships *cased with armour* and *equipped as rams*, this question takes the very first place. If any single ship possessed powers such as those which the steering screw may be expected to give, in conjunction with those of an iron-cased ram, she would be the terror of a fleet; and the issue of an engagement between two ships thus constructed would depend less upon the power of their artillery, and the amount of protection given to the guns, than upon the facility with which the vessels could move and turn, and upon the provision made for resisting the blows of the ram. There would be but little time or opportunity for fighting guns. The engine and the steering apparatus would do everything. Although in the view of operations against fortresses and forces on shore, the armour and the ordnance must still hold the first place, yet the vital necessity for the English Navy will always be, the means of maintaining supremacy upon the sea, in order to secure our own coasts and commerce.

Nothing can apparently be more desirable for England, than such a change in the conditions of naval warfare as that indicated, for a few rapid iron-cased rams would render the transport of large bodies of troops across the Channel so hazardous as to make invasion next to impossible; and this change would also possess the advantage that large crews would become both unnecessary and undesirable, it being the duty of the constructor to furnish the small crew with the means of resisting capture by boarding. But all this lies in the future, and depends upon improvements in the machinery of steering.

I beg now to leave in your hands the various questions I have raised, only adding that I have no interest in any of the plans I may seem to have recommended beyond that which we all feel, and which springs from an earnest desire to increase the efficiency of the English Navy.

The principal questions I have proposed for consideration are as follows:—

First, with regard to the ordinary rudder in single screw ships,—can any improvement

in the ordinary rudder, either in its form and dimensions, or in the mode of applying power to it, be expected to give us such facilities in steering as the exigencies of modern naval warfare demand; and if such improvement may be expected, in what direction is it to be sought?

Secondly, with regard to balanced rudders,—looking at the great number of men required to work the rudders of large single-screw ships, at the loss of power by the leverage of the rudder, at the loss of efficiency through the smallness of the angle at which these rudders can be worked, and at the slowness with which such rudders can be put over, would it be desirable to substitute for them a balanced rudder in ships where the stern-post may be removed and the rudder put immediately abaft the screw?

Thirdly, with regard to double screws,—supposing there is a loss of time in completing the circle by the aid of the double screw, and a little loss of speed, is the advantage of being able to turn in that circle, without being compelled to move ahead, sufficient to render its adoption in large ships of war expedient?

Fourthly, with regard to a steering screw,—if a steering screw, working transversely in the bow of the ship, regarded in the crude state in which I have presented it, promises to give the same advantages as the double screw with regard to turning on a pivot, and promises also to increase the rapidity of turning—an advantage which it seems impossible to secure in any other way; and, further, if a steering screw may be employed when the vessel is not under steam, does it offer sufficient promise to make a trial of it desirable?

DISCUSSION.

The CHAIRMAN (J. Scott Russell, Esq., Vice-President): We have now, according to pre-arrangement, a full hour to give to the discussion of this question. I venture to say, I think it would be expedient if the gentlemen present who are able to contribute to our knowledge would take up the subjects as they have been brought under notice in the Paper, and give us their decided opinions upon them.

Rear-Admiral Sir EDWARD BELCHER, C.B., Assoc. Mem. Council, I.N.A.: Before accepting the assertions which have been advanced as to the steering of ships, it should be stated that the vessel selected was a "stubborn brute," and one which seemed to defy the ordinary persuasion of seamen. Most seamen, even with these apparently unmanageable craft, generally contrive eventually to make them steer almost independently of the rudder. The subject of this discussion is a seaman's question entirely; and every practical man knows that by trimming his ship, sometimes by the head, and sometimes by the stern, the rudder is so materially aided as to require to be put "hard over" only in cases of emergency. Some officers have their ships in such beautiful trim that, to use a seaman's phrase, they "could run the flying "jibboom into the eye of a needle." Indeed, the great duty of the thoroughly practical seaman is to

manage his ship solely by the sails when he has lost his rudder; and I believe there are officers present who know that the general order in the ships which I commanded was that, "the helm was never to be "used in tacking ship unless to avoid a manifest danger." I had to deal with a ship, which, when I first took command, frightfully disturbed the chronometers by concussion of the rudder. She would not steer, and was unsafe. In forty-eight hours she was cured, and moreover, sailed infinitely better.

Now, looking to the form, and the various degrees of force, and its direction as brought into play on the whole area of the rudder, it occurred to me about the year 1822 that the direction of the current on the rudder was a matter which deserved a much closer investigation than had been bestowed upon it. Every curve of the after section carried the opposing fluid at angles of incidence from the keel upwards on to the rudder's surface, so as to produce different degrees of force; and I found that when the rudder was cut away at the lower angle, and carried by a curve up to the water line, filling up the space by the area subtracted from below, steerage was more easily effected.

I commenced this subject as early as 1815; and at Bermuda between the years 1822-24, I had so far succeeded as to induce many practical officers to follow the improved form which I introduced into the Navy, and now see adopted in the models before you. I would also observe that the idea of steering, even a boat, by *force of rudder*, is utterly repugnant to the feelings of all good seamen; and also that it materially impedes the speed of the vessel.

I took my original ideas of the action of rudders in 1815, from Lieut. Shuldham, R.N., the son of the talented General Shuldham, Royal Engineers. He produced a launch fitted with sheer masts on a turntable, but without any perceptible rudder. He steered with a harpoon-shaped instrument which passed through the keel of the vessel about one-third of her length from the stern, and he turned her on her centre with wonderful celerity, as many officers who served at Spithead in 1819 may recollect.

In 1830 all the boats of H. M.'s ship *Etna* had their rudders cut to the form which had been proposed by me. In the same year, when I was directed to fit H.M.S. *Etna*, I applied to have the rudder altered. Sir Robert Seppings would not comply with my request, but urged the impropriety of adding area at the surface of the water. Sir Michael Seymour, then Commissioner, considered that I had adequate power to make the alteration, and Admiral Hayes also coincided with him. The alteration was made and proved highly advantageous.

If the *Warrior* cannot steer with facility, and indeed, celerity, her broadside guns will be useless, and she will be at the mercy of her antagonist; but with double screws and rudders she might be made a much more serviceable vessel.

Reference has been made to the performance of the *Flora* and *Kate*, vessels which have twin, but independent screws. I was present with many brother officers and men of engineering talent at the trial of the latter vessel, and it was our opinion that if she had been constructed on the lines of our ships-of-war of the corvette class, her performance would have been even wonderful. The *Flora* had better lines than the *Kate*, and therefore, her performance was superior. Moreover, the screws of the *Kate* were not sufficiently immersed, the blades on starting being 6 inches out of water. The experiments of (I believe) Mr. George Rennie proved that the power increased with every foot of immersion. I feel satisfied that the double screws must eventually succeed; and especially with regard to quick delivery of fire, the broadside vessel could deliver her separate shot by an entire revolution in 3 minutes 24 seconds, and *leisurely reload;* while such practice would be impossible by any other vessel.

During the last year many plans for facilitating steerage have been submitted to me for my opinion.

There was one in particular by a Mr. Curtis, which I understood had been reserved for trial by the Admiralty. The plan consisted in adding the entire power of the screw to the radial angle given by the rudder. In the ordinary construction we have an additional rudder post; but in the plan proposed by Mr. Curtis there is only the old stern-post, and that is cut away to permit the action of the screw: a similar curve is cut out of the rudder to receive the after bearing of the screw, the stern-post bearing being worked by the ball and socket, or variable joint. It is evident that this action will be always exactly at right angles to the line of the rudder, and so force the vessel round. It may answer in gunboats, and in vessels which can be docked with facility; but the arrangement prevents the lifting of the screw, and involves too many disadvantages for it to be adopted in large vessels.

I made drawings for canal vessels in 1818, which were to be propelled by ejecting water abaft. Experiments which were made proved that even a run of water from a foot aperture would give a line-of-battle ship steerage way. A model consisting of two long iron cylinders like the double canoe of the South Seas was tried on the New River in 1833 (*vide Nautical Magazine*). A tank was placed between them, and a 6-inch aperture permitted the water to escape 2 feet above the line of flotation. A velocity of three knots was obtained. I have, therefore, looking to the motions of mollusca and fish, a strong impression that jet tubes carried out on the sides of the rudder, or openings under each counter might be used with success for aiding the rudder, and probably for turning in a very much shorter interval. But the turning alone is not the grand desideratum: we require the utmost facility for direct steerage, and without strain on men, rudder, or stern-post. We require a most careful and elaborate system of experiments to determine all these points. I am not quite satisfied with the assumed motions resulting from the action of the rudder. In the experiments with the *Kate* the bow certainly moved and so did the stern, but the latter was assuredly the most active; and it was particularly observable in that vessel as she quitted the pier on her late trial. Her stern "hugged" the piles, and it was necessary to be very cautious in using the screws. All these are matters of the highest interest to professional men; and I hope before long to learn that the necessary experiments have been undertaken and carried out by the Government under the supervision of seamen whose competence in the handling of the craft cannot be disputed.

Mr. Charles Lamport, Assoc. I.N.A.: I think a distinction should be drawn between the steering power of vessels propelled by steam, either with screw or paddles, and those which are propelled by sails only. I think in both cases the effect upon the rudder may arise from the same cause. Putting on one side the difference and degrees of angles, we must consider that the effect of the rudder will depend upon the resistance of the water it meets with at whatever angle it may be placed; and that with a larger or smaller angle, the same result would be produced upon the steering of a vessel. Surely in the case of a screw ship the pitch of the screw must have an important effect upon the action of the water impinging upon the shafts of the rudder. Whatever may be the angle of the rudder, if the helm is hard over, and if the water be thrown upon it in the line of the ship's keel, it would produce one result; and if thrown upon it in the line of the surface of the rudder it would produce another result. In ordinary cases if you take the angle of the pitch of the screw at 45°, the water thrown up from both those surfaces must be thrown away from the direct line of the vessel, or must be thrown in the direct line of the rudder, so far as regards the effect of the pitch of the screw with respect to the steering. It, therefore, appears to me that the placing of the rudder in relation to the screw is a most important element in the steering of the ship. If you place the rudder away from the screw, you place it in a mass of water differently affected than when you place it near the screw. The same effect shows itself in the steering of sailing vessels. The form of

the helm is, I think, a most important point. Admiral Belcher, in my opinion, erroneously states that the water rises up to the stern of the vessel.

Sir E. Belcher: Horizontally.

Mr. Lamport (*continuing*): Whatever it may be, I think the discovery made by Mr. Ransom in some experiments which were suggested by the curious effects of the action of the screw, is a very important one. It was shewn that the course of the water at the after part of the vessel was at right angles with every part of the ship. If she has a fine run, water must be passing to fill up the vacuum; and the water flowing in at right angles may be flowing away from the surface of the rudder which ought to catch it to turn the vessel.

I think in an Institution like this the effect of the angles of the run of the ship ought to be carefully considered in determining the form and extent of rudder of a sailing vessel. My opinion is, that we should take the various angles, and form the rudder in relation to those angles, considering this, that the deeper we go down the less disturbed is the fluid to which we come, *i. e.*, it is *dropping* into the course of the vessel at right angles to its course. At the upper part, we may have it flowing in the direction of the vessel itself. The deeper we go, the stiller will be the water caught by the upper surface of the rudder. The effect, therefore, upon the lower part of the rudder will be greater than on the upper, and on that account it will have to do more than the average work; and to make the rudder of a sailing vessel work without shock we must fine away the lower part, so as to cause the work done by it to assimilate to that done by the upper part. But when we come to the surface we have another difficulty, namely, the action of the waves upon the upper part of the rudder. We must, I think, cut it away there, to prevent that "jerk" which would throw a man overboard in an ordinary sea.

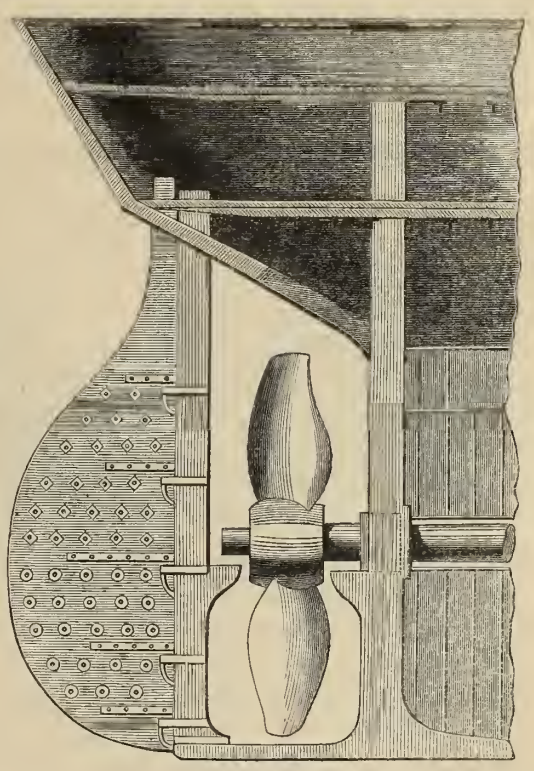
I should be glad if any gentleman present could inform us as to the curious effect of putting on the two ribs, or the hollowing out the back of the rudder in vessels that steer badly, and of which the rudders have shaken so as to occasion great disturbance.

Capt. De Horsey, R.N., Assoc. I.N.A.: We have been told this evening by Mr. Barnaby that it is impossible to turn a ship without a large sweep occupying a long time. That a large sweep will occupy a long time, I do not dispute; but as a practical man, I would say that a ship may be turned in her own length. I have done it myself when at a distance of not more than the length of two ships from a coral reef and a heavy surf. I gained my knowledge in this respect in a very good school under Admiral Fitzroy. I have seen him throw a log of wood over the gangway, and steer round it, the log not being a stone's throw from the gangway any time during the passage round; and to do that requires no more skill or knowledge than is possessed by most naval officers. I say this without any disparagement of the plan of two screws, which I have no doubt will afford great facilities for turning; because the method of turning by one screw is a slow proceeding: notwithstanding which, it can be done. We must not suppose that a vessel need make that circuit which has been attributed to the *Warrior* to get to the centre of the circle. With regard to the steering of the *Warrior*, I would say that the draught of water is not in proportion to her dimensions, as compared with smaller ships; and, therefore, we cannot expect the rudder to act as well. I have also one remark to make about the lower part of the rudder. It is a point which has been long disputed, whether the lower part of the rudder is of any use whatever. When in command of a ship, I took upon myself to make it larger, but after a time, I came to the conclusion that I was wrong in so doing, and that the lower part of the rudder was of very little use. The reason for this is, that the lines of the ship being finer below, the water there does not strike the rudder with the force it does nearer the water line; and that the lines being fuller towards the water line, they have more effect in turning than those down by the keel have.

Mr. Thomas J. Ditchburn, M.I.N.A.: I have had a great deal of practical experience with rudders for many years past. So long ago as the year 1820, the balanced rudder was exhibited in the Dockyard at Chatham, before Sir Robert Seppings. I recollect being present as a youth to witness an experiment upon it, and it struck me forcibly that it was the right thing to adopt in the navy. The result of this experiment, however, was that Sir Robert Seppings considered the rudder too delicate a part of a ship to be interfered with, and therefore, he declined to have anything to do with the introduction of the kind exhibited. I have tried the balanced rudder myself, and have found that it enabled me to get rid of the stern-posts; and, speaking in the case of a steam ship, she could be turned by just putting the wheel a little out of the middle line to allow the water to pass between the fore part of the balanced rudder and the after part of the vessel. I have fitted that kind of rudder again and again, and have always achieved the same results. I fitted a steamboat on the Rhone with a rudder on that principle, and in turning about, while going at full speed, she snapped the shaft completely in two. I saw the plan adopted in sailing vessels thirty years ago, and Mr. Holdsworth applied it to a yacht with equal success. From all I have seen and thought upon the matter, I think it is the most effectual rudder that can be applied to screw steamers.

Capt. T. E. Symonds, R.N., Assoc. I.N.A.: We have been invited by Mr. Barnaby to suggest any other form of rudder that may have occurred to us. I will therefore mention one with which no doubt some persons present are familiar. It is that which has been adopted for centuries by the Chinese in their vessels of every denomination, many of which, from their very peculiar form, are most difficult to steer.

Fig. 1.



The Chairman: The differential rudder?

Capt. Symonds: No, not precisely that. Most of their vessels (junks) are remarkably square and full abaft, and require a very large rudder which is often lowered below the bottom. This rudder, from its enormous size and want of support, could not be readily used were it solid. It is therefore perforated with either round, square, or diamond-shaped holes (in some cases looking more like a grating than a rudder), in order to facilitate the operation of steering, which is by this means easily accomplished; whereas, without them, it would be almost impossible. I have for some time been inclined to believe that this principle might be adapted with advantage to the rudders of our large ships. Fig. 1 of the accompanying diagrams gives us an example of such an application to the rudder of the *Warrior*, which, when even increased in area and perforated as shewn, with diamond-shaped or round holes, would be got over more readily by manual power properly applied, than the present rudder would be by either steam or hydraulic power.

In the event of the rudder being struck by a sea when lifted out of water, or when the ship is taken

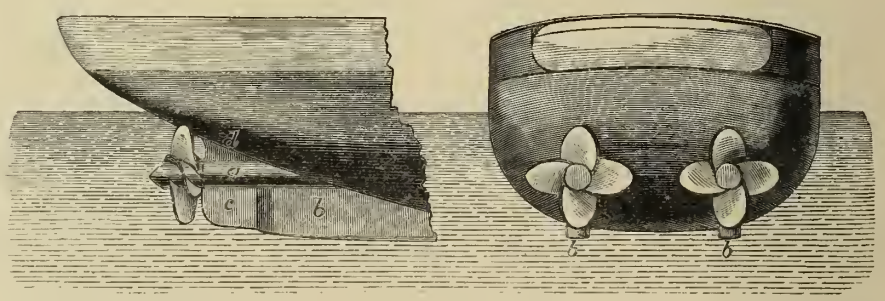
aback, or gathers stern-way rapidly with the helm over, the risk of straining the rudder-head and post, or the pintles, would be greatly reduced by the water passing freely through the holes. The slots or holes as shewn in the diagram, whether circular or diamond-shaped, increase in size from the centre; that is, are countersunk on both sides. When the helm is put over a series of surfaces are thus acted upon nearly at right angles, and the perforations allow the water to pass freely through them in the act of putting the rudder over. The lateral resistance is redueed, and less power is required to actuate it: the steering effect is greater, the rudder being got over to a greater angle in less time. However, be the cause what it may, the effect is the same whether in Chinese junks requiring large rudders, or in an English man-of-war.

Of this we have some experience. The *Glatton* armour-plated battery on her outward-bound voyage to the Mediterranean steered so wildly that she was almost unmanageable. At either *Malta* or *Gibraltar*, I forget which, her rudder was increased considerably on the after edge, I believe nearly one-half, *the whole being perforated with 6-inch holes, after which she steered well.* I hope I have said enough of my perforated rudder to invest it with some degree of interest. It has been remarked that the water does not act on the lower part of the rudder in the same proportion as on other parts. Now it appears to me that the Chinese practice proves that it does, it being found necessary to lower the rudder below the bottom of the vessel in order to steer efficiently. I have noticed very lately several trading schooners in the Thames that have a considerable increase of area on the lower part, and which has improved their steering especially in shallow water. I think therefore the remarks that have been made on this question are not borne out in practice.

The CHAIRMAN: Perhaps it is different according to the different shape of the vessel.

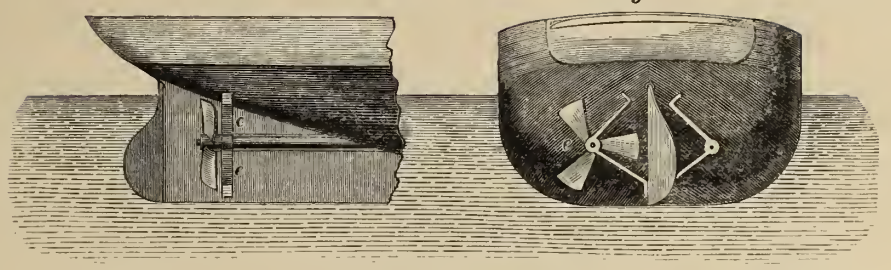
Capt. SYMONDS: It may be so, but I do not think that affects the question generally. I hope I may be permitted in the absence of Mr. Richard Roberts who more particularly represents the system of fitting "twin screws" as shewn in Figs. 2 and 3, to call your attention to that method, it being, I consider, a more mechanical, stronger, and simpler arrangement, and one less liable to accident than that now used. You will observe that by this method the dead wood, stern post, central keel, and ordinary rudder are dispensed with. The screw shafts are led through the trunks *(a)* which are under the quarters and which are firmly secured to the bottom by vertical webs. These trunks are of considerable diameter at their fore end, gradually diminishing to the diameter of the boss of the screw which fits close to their after extremity. Under these trunks are fitted two cellular keels *(b)* of any required width and depth running under each bilge nearly the whole length of the bottom: these keels will contribute very materially to the security of the trunks, the rigidity of the after body in the wake of the screws, and to the general strength of the bottom which they defend on the vessel taking the ground, keeping her from falling over. Under canvas they will give stability and weatherly qualities. It has been proved that two keels so placed do not interfere with steering or turning. You will observe that

Fig. 2. *Fig. 3.*



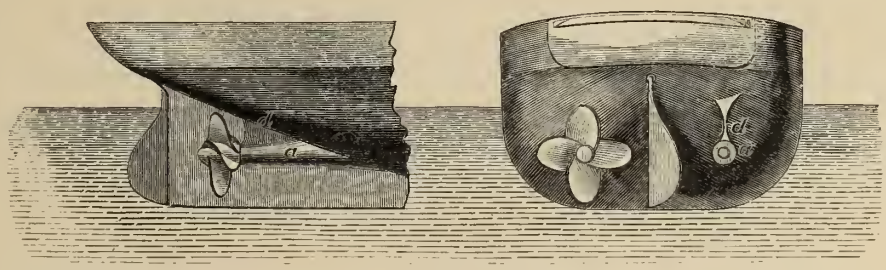
there are *two* rudders fitted to the after extremity of the keels, as shewn at *c*, Fig. 2, the united areas of which will generally be in excess of the immersed area of the ordinary rudder in a single-keeled ship. These subaqueous rudders act in unison or separately as may be desired; and being constantly submerged they are not liable to injury, and their action is constant and uniform.

Fig. 4. *Fig. 5.*



In this arrangement the water will have a more undisturbed flow to the screws in all directions than in the single-keeled ship with the screws fitted with the outrigger V brackets, as shewn at *e*, Figs. 4 and 5, and the screws having more space to work in by the absence of the "dead wood," their efficiency will be enhanced. The area of resistance to turning is also decreased by the absence of the "dead wood." The screws and rudders are in a position to develope their maximum effect, both being immersed so as to avoid most of the dangers to which the rudder and propeller of a single-screw ship are liable from floating wreck, and other contingencies. This method of fitting will, I believe, be found lighter and stronger, and less expensive than any other. There can be no objection to placing the screws abaft the rudder as shewn in Fig. 2. There is nothing novel in placing a screw abaft the rudder, and in the case of the *Prince Albert*, built by Mr. Dudgeon, and several other vessels, the screw so placed gave a better result with total absence of vibration, and the steering power was as perfect as in a sailing ship, there being no screw aperture for the water to escape through, instead of impinging on the rudder. Figs. 6 and 7 represent our plan of fitting single-keeled ships with twin screws, substituting vertical, or horizontal webs for the V brackets.

Fig. 6. *Fig. 7.*



Having been an eye-witness of the performance of the *Kate* and *Flora*, I can confirm what has been said as to the extraordinary steering and turning qualities which these vessels exhibited. They are not, however, ships that I should have selected to illustrate the full value of the principle, being narrow and very high out of the water; in fact, light, with a great deal of top hamper, which being acted on by the wind has impeded their *turning* very materially.

In an armour-clad or any other ship of war, when the weight of hull would be much greater in proportion to the height above water, and the screws necessarily farther apart in a vessel of great beam, the advantages of the twin-screw system would be developed to a much greater extent, both in propelling and manœuvring, and I believe the larger the ship the more apparent would be the utility of this method of propulsion.

The form of screw is a point on which I wish to say a few words. We have hitherto seen no means

applied by which "fouling the screw" is prevented, and yet it is a most important point. Indeed, I may say a pressing necessity.

The screws shewn in Figs. 6 and 7 are on a principle which my friend Mr. Roberts and myself have recommended for several years; it is, you will perceive, a four-bladed screw, the blades being of wrought iron or steel of a spiral form, and calculated to throw off any impediment; it is in fact, *non-fouling*, and therefore, I submit, well worthy the attention of this Meeting, or any one taking an interest in naval matters. I see no reason to doubt its producing as good a mechanical effect as any other propeller. I believe that it will produce a better effect, especially when fitted to the trunk in the manner I have before described, as the water flows in an uninterrupted volume along the trunk direct to the blades, whereas in the ordinary screw the boss displaces much water, and in many other ways works at great disadvantage in the centre of the wake: in an eddy in fact. Recent trials have proved that its having four blades can form no objection: although the point has been raised, I maintain that the form of this propeller will not only prevent fouling but will ensure a constant and uniform action—one that must decrease, if not entirely prevent vibration.

The twin-screw system must prove a great auxiliary for war purposes, especially for sea-going ships in which broadside guns must still be adhered to. I believe Mr. Reed has very correctly stated that no sea-going ship can be found to carry the top hamper required by the cupola system in a heavy sea. For my part I cannot see the necessity for cupolas in a sea-going ship, the broadside guns of which may be brought to bear with the same accuracy and speed as those in the cupola, by the application of the twin-screws.

Mr. Andrew Murray, M.I.N.A.: I can corroborate what has been said by Captain De Horsey. I think the power of a vessel in turning with the ordinary screw has been underrated. On the occasion of the steam basin at Portsmouth being opened by Her Majesty, the *Fairy* was brought into the harbour and turned round without going ahead. I again saw the experiment tried at Spithead. A log of wood was thrown overboard and the vessel was made to keep alongside that piece of wood while she turned. With respect to vessels of war in action, I cannot say at what distance from each other they will hereafter fight: if they fight as close as they did in the last war, even supposing the case put by Mr. Barnaby of vessels having a difficulty in turning round, the way they would go in 100 or 200 yards would not be such as to expose them to much harm from the broadside of an adversary. Taking the *Warrior* and the *Black Prince* for example, they would be turned on a pivot by means of the screw which I have spoken of in two and a half minutes—the time which it is stated they would require to make the quarter circle.

The Chairman: Perhaps Mr. Dudgeon can tell us whether two screws can be made to act with a better effect than one in giving speed to the ship.

Mr. Dudgeon, Assoc. I.N.A.: I cannot tell you that; but I can say that what Sir Edward Belcher has stated with regard to the performances of the *Kate* is quite correct. She was not, however, a vessel fit to be experimented upon, to exhibit the power of two separate engines turning the vessel by two separate screws. The *Kate* was, comparatively speaking, a perfect log of a vessel without the form to make such evolutions. I quite agree with Sir Edward Belcher, when he says that, if you put two screws with separate engines to a vessel properly constructed, you will then be able to obtain a result which has never before been obtained in the power of moving a body through the water.

The various opinions I have heard this evening on this matter strike me as being remarkable. The bare idea that a vessel can turn round without a rudder, or its equivalent, is more than I can understand.

This I know, that if I make a body in the form of an equilateral triangle, and double it, and put a screw at each end of the two angles, one to go ahead and the other to go astern, that body must stand still for ever; but the moment I put a rudder to either of the two angles, and turn it so that a current is directed against that rudder, and I also detract from it the other current opposed, I then add to the force of that rudder in proportion to the force that the two currents have added to each other. If I elongate the body, as we did in the *Kate*, I then find that the work to be done by the rudder is in proportion to the additional length, the beam being the same. The *Kate* took more time to turn round than the *Flora*, being 15 feet longer, and of the same beam. I mean, by these observations, that even with double screws the rudder is most to be depended upon. In practice, I find that without the rudder, the vessel takes double the time to turn that she does with it. I am sure no single screw will turn a ship as fast as two screws will, one going ahead and the other going astern.

Mr. JOHN GRANTHAM, Mem. Council, I.N.A.: It is very unfortunate in the history of all these balanced rudders that they have been tried and have then disappeared. Mr. Ditchburn has given us one instance of this. I will give you another:—The *Great Britain* had a rudder almost like the one described. For some reason it disappeared, and all the benefit derived from experience was lost. The advantage of this rudder in the *Great Britain* was questioned, and when she got ashore in Dundrum Bay, it was knocked away, and not again put on her; but a solid stern-post was fixed to her. One reason which I heard, was, that the captain said she did not steer well. Another was, that when she went ashore the slightest touch of the bottom entirely deranged the rudder; and it was apprehended that even a slight accident would have a similar effect. The opinion I heard from the captain was adverse to the rudder; the general statement being that it was very easily moved, but the ship steered badly. I do not think it was investigated with that care which should have been given to the question, seeing how very important it was. This directs my attention more particularly to one point. I think Mr. Barnaby gave a proportion which had been derived from experience of how much the after part of the rudder required to exceed the fore part.

Mr. BARNABY: Two to one.

Mr. GRANTHAM: Supposing they had been equal, what would have been the result?

The CHAIRMAN: Nobody knows.

Mr. GRANTHAM: It is a pity it has not been tried.

Mr. DITCHBURN: I have tried one-third of the rudder before and two-thirds behind.

The CHAIRMAN: What was the result?

Mr. DITCHBURN: It stopped the ship's way.

Mr. GRANTHAM: Supposing the tiller had been kept by force in that position?

Mr. DITCHBURN: It would have had a material effect upon the speed of the vessel.

Mr. GRANTHAM: Then there is some counteracting effect in the rudder itself?

Mr. DITCHBURN: There is a counteracting effect if it is badly proportioned—if you make the fore part too broad.

Mr. GRANTHAM: Then I conclude that the fore part of the rudder has some disadvantages?

Mr. DITCHBURN: If made too broad.

Mr. GRANTHAM: If it will not answer when the same area is put abaft as before, it is clear one counteracts the other, and it is a point to be thought of. I would ask Mr. Barnaby to think that matter over.

I will now say a few words about the double screw. The double screw is not a new plan, but on the contrary, a very old one; it is an old thing revived. Great praise is due to Mr. Dudgeon, and to any one else who puts his hand to such a work as this so as to commend it to the public mind.

The CHAIRMAN: It is as old as the screw itself.

Mr. GRANTHAM: It has been generally adopted in America, and the results have been very good. The object sought was to have a screw to act in a light draught of water. Both these screws may be brought far out of the water. I have seen screws where the dip was only like that of an ordinary paddle-wheel, and in such cases the vessel steered well, because the screws were put so as not to affect the steering. I have myself devised a powerful screw only drawing about 15 inches of water. I have not yet executed it, but I think I shall. It is intended to go through locks, but as to the steering effects, I think it will have important results if carried out as suggested by Mr. Barnaby and others, for ships of war. Mechanically, it must have the effect of turning the ship, for we know in paddle-wheels this is really the case, though to a much greater degree. Many tug boats are made to turn the wheels independently of each other, and we often see boats turning in the river without making any headway. I feel it important the screw should be adopted, because I think the disadvantages are not great. Many years ago I saw a wooden ship from America with two screws. There is a great disadvantage in having two screws in timber ships, as they make it obligatory to cut several of the timbers in each quarter to admit of the screw-shaft passing out. In an iron ship there is no such difficulty. The amount of resistance from the framework will not, I believe, greatly exceed the amount of resistance of the ordinary rudder-post. I think the double screw, as a principle, is very important. The balanced rudder is a good thing, probably; but I think it has not been sufficiently investigated, and I should recommend the Government to try experiments, which would be inexpensive and simple.

Mr. EDWARD HUMPHRYS, Assoc. I.N.A.: I have had my attention drawn to the subject of the steering of vessels at the measured mile; and I have noticed that the difficulty of getting the rudder over arose from the want of proper power to put it over. If the rudder is put over to 45°, I believe the ship will turn as quickly as is wanted; and there is no difficulty in putting the rudder over if you employ proper mechanical power to do it. I am fitting six of the Peninsular and Oriental Company's ships, each over 2,000 tons, with machinery for putting the helm hard-a-port and starboard.

The CHAIRMAN: With hydraulic power?

Mr. HUMPHRYS (*continuing*): Yes, with hydraulic power; and while the vessel is under weigh the helm can be put from starboard to hard-a-port in twelve seconds. I cannot help thinking that there is a good deal of imaginary difficulty about the steering of ships. We have been increasing the size of our vessels, and have still employed the same means for steering that we have been accustomed to adopt in much smaller vessels. As to manual power it is out of the question, for you cannot get twenty men to act altogether; and the remedy in my opinion is not in the pitch of the screw, nor in the introduction of the manœuvring screw, but in large ships to have the necessary apparatus for putting the rudder over when it is required to be done.

Mr. BARNABY: The experiments of Captain Key were made in this way: he first had a rudder constructed with a total area of 35 feet, and having the area of the after part in proportion to that of the fore part as three to two. He found that with this proportion the fore part of the rudder was too large: because, apparently, it was nearer the screw than the after part, and was acted upon more powerfully by the water. He found it difficult to get the rudder amidships from an oblique position. He then made the

area of the fore part one-half that of the after part reducing the area to 30 feet, and ultimately to 20 feet; and he found with that proportion he had as good a result as with 35 square feet.

With regard to the statements made by Capt. De Horsey and Mr. Murray as to the possibility of turning these large vessels round (as I understand them to say) almost in their own length, I can only say, that in the experiments made upon the ships I have mentioned, the *Warrior* and *Black Prince*, the following were the diameters of the circles in which they were turned when under the greatest power of screw and rudder, 858, 813, 983, and 960 yards. I must say I am delighted to hear, after all that has been said of the *Warrior* and *Black Prince* that they can be turned in their own length.

Capt. De Horsey: What I said did not apply to the vessels under weigh.

Mr. Barnaby: It is an advantage I never thought they possessed, therefore my criticism upon those ships must be considered to refer to them only when turning under weigh.

With regard to Sir E. Belcher's remarks as to the advisability of ejecting water from the bow or stern for turning a ship, it would amount to what you see in this diagram, (Fig. 5, Plate II.) the ordinary screw being really a jet propeller in the best conceivable form.

With reference to the invention of Mr. Curtis in which the screw is put in the rudder, I would say that ten or eleven years ago I saw a model of a vessel made in that way, in which the screw was so placed with a universal joint at the axis of the rudder. It would no doubt have acted well but for the difficulty attending the use of the universal joint. Then as to forming the sterns of ships with a view to the action of the water upon the rudder, that is out of the question. We must do the best we can with the rudder after the form of the stern has been determined by other considerations.

Mr. Ditchburn: Mr. Barnaby has no doubt heard of the friction of rudders. I have seen a form of rudder designed to take off the friction which is supposed to exist in the body of the rudder. The idea was that the friction was material, and to keep out the water from that part of the rudder, a series of copper plates was invented and screwed to the main rudder. They went out, and kept their places against the rudder: but when the ship was deeply laden the upper parts of the plates laid themselves against the bottom of the ship, and she came home to the East India Dock in that state, destroying the effects of the water upon the full load line.

The Chairman: I am sure you will all join in hearty thanks to Mr. Barnaby for his thoughtful, very valuable, and very discriminating Paper. I think we may gather from the discussion a great deal of good. In the first place I think the observation Mr. Humphrys made is a valuable one. I am disposed to think that much of the pains hitherto taken to improve the steering of ships in the Navy has been entirely thrown away, by being expended, as Mr. Barnaby says, in trying to get more out of ropes, barrels, and men than is in them. It is all very well when you have nothing but ropes, barrels, and men, to consider what is the best use you can turn them to, to produce the best effects: therefore it is quite right when you have a limited power of this kind you should search out how you can get the greatest effect out of it. I would rather that the Admiralty treated the question now in the form Mr. Humphrys has indicated; that they should provide for the ship a superabundance of absolute mechanical steering power. Having put that into the ship, you would next compete with the difficulties pointed out—that you had made your ships desperately long and comparatively shallow abaft; and that you had enormously diminished the steering power in proportion to the dimensions of the ship. You can only compensate that, by making the rudder very long and big. I should be much surprised if a 14-knot ship with a big rudder, and as much power as

you please to apply without danger to the ship, could not be made by a clever captain to do anything but speak. I think it could; and therefore I would say if you want to improve the steering power of a ship in the simplest way we know how to do it, be careful to make her stern and everything about it strong enough; then put in a rudder big enough and strong enough; and then put in so much mechanical power as will, as rapidly as Mr. Humphrys says he can do it, put over the rudder to the angle that is wanted. If anything is wanted after that we must see how to get it. But allow me to tell you why I think you will not get anything better. It is for this reason: that in the run of big ships, going 14 knots an hour, you have in the current of the water an enormous power applied just at the place you want it; and I say do not throw away this enormous power, but put something which is big enough to use it all for the purpose you require. I am afraid of differential rudders for high speed; I have tried them. They are a dangerous kind of power. They go over, and are held over very easily; but are liable, from the current taking the front part, to go over and stay over; and when over they are so liable to enormous forces either from getting across the stream of a vessel when going rapidly or from the action of a wave, that I am afraid it makes it a source of serious danger. I believe it is not well, for this reason, to carry the differential principle too far. I believe the differential rudder, carried out moderately, has advantages. It enables you to exercise an enormous effect upon a ship with comparatively little power at the end of the rudder. But I will tell you why I like the ordinary shaped rudder. It is, that when anything happens that you do not like, whether from the sea or other causes, it yields more easily to any force which otherwise might destroy it. With regard to the use of the rudder-post, I have been rash enough to dispense with it long ago. I never could see how a rudder-post, as it is called, could give any help to the stern of a ship, more than is contained in the word "post." In my opinion you could not invent a more helpless thing than the rudder-post of an iron ship. The rudder of the *Great Eastern* was made to strike hard upon the screw and upon the rudder-post in a heavy sea. When a wise captain got her into the trough of the sea, the rudder simply knocked out the stern-post which was in its way, and left it there; and as they met, the screw going on with the rudder inclined the contrary way, the screw and the rudder had a fight, and each hacked a great many pieces out of the edges of the other. However, I found that the screw with its hacks was as good as before, and the rudder the same, and no harm had come to the ship. The helm is pivoted at the bottom on an upright after-bearing, which goes into a cup in the bottom of the rudder, and that holds it in its place. Then above the screw aperture it is held by a strong *clip* to the stern of the ship, to what you may call the heel of the ship, although not more heel than Mr. Barnaby represents. The rudder then, in an iron vessel is capable of being made far stronger, far more powerful, and far more durable than by any rudder-post which you can put there to hold it. The bow rudder I have also tried. I think it is about the most hopeless thing you can have. I had a ship made to go either way, and she had a rudder at both ends of her. The rudder in the bow was fixed; and some clever person was amusing himself at the bow of the vessel, and amongst other things, pulled out a bolt which he did not know the use of. Immediately the bow rudder flew round, and notwithstanding the stern rudder was put hard over, the ship went on to the bank before she could be stopped. The bow rudder, I think, is of very little use, and in most applications comparatively dangerous; nevertheless, I think the bow rudder very long, and at a slight angle, has a certain amount of effect. I would rather, however, put a little more rudder on the other end. The discussion which has taken place and which will be recorded in our *Transactions*, is a very valuable one; and I am pretty sure I may convey the best thanks of this meeting to Mr. Barnaby for his Paper.

ON COPPER AND OTHER SHEATHING FOR THE NAVY.*

By W. J. Hay, Esq., F.C.S., Assoc. I.N.A., Admiralty Chemist and Lecturer, Royal Naval College, Portsmouth.

[Read at the Fourth Session of the Institution of Naval Architects, March 26th, 1863; J. Scott Russell, Esq., F.R.S., Vice-President, in the Chair.]

Although I most cheerfully comply with the request of your Secretary to read a Paper to this Institution, yet I feel much diffidence in doing so, lest I should not sufficiently do justice to so comprehensive a subject, it being one of national importance with regard to economy, and of the highest interest to the mercantile marine.

I shall endeavour to give as briefly as possible the various proposals and plans which have been suggested and carried out from time to time for sheathing ships and other vessels.

I will first allude to the fact that wood sheathing was used in the 15th century for two purposes, *viz.*, to keep the soft caulking formed of oakum and tallow from coming out, and to prevent the destructive action of the different species of sea worms.

Experiment was next made to a considerable extent with lead sheathing; and in 1670 an Act of Parliament was passed granting to Sir Philip Howard and Francis Watson the exclusive privilege of manufacturing milled lead for this purpose. Twenty ships were sheathed with lead fastened with copper nails; and it was not wholly discontinued till 1770, when the *Marlborough* on examination at Sheerness was found to have lost all the sheathing, except a small portion on the bow knee and the rudder.

In a work on Naval Architecture by Leon Battista Alberti, and which was written in the 15th century, it is stated that, "Lead sheathing was used in the 2nd century, and "that while Trajan was compiling his work, his ship was weighed out of the Lake of "Riccia where it had lain sunk and neglected for above 1,300 years." He observed, "that the pine and cypress of it had lasted most remarkably. On the outside it was "built with double planks, daubed over with Greek pitch and caulked with linen rags; "and over all there was lead sheathing fastened on with little copper nails."

* Received March 23rd, 1863.

After the examination of the *Marlborough*, wood sheathing was generally used. Experiments were afterwards made with copper sheathing. Several methods of rendering it more durable, as well as of checking the growth of sea weeds, were adopted, such as filling the sheathing with nails so as to form almost an entire metal sheathing, and paying them over with compositions suggested by different persons. In 1737 several compositions were tested at Portsmouth, and ultimately, one made of pitch, tar, and brimstone, was deemed the best adapted for the purpose, and was generally used for graving.

In October, 1761, the Admiralty determined to try Copper Sheathing for the Navy, and ordered that H.M.S. *Alarm* should be sheathed with thin copper. This vessel proceeded to the West India Station, and after a sufficient time had elapsed for the result of the experiment to be determined, she was examined. The sheathing was then found to have answered well in keeping the bottom comparatively free from the adhesion and growth of barnacles, &c. It thus appears that the first ship coppered, was the *Alarm*, in the year 1761. The second was the *Aurora* in 1765, and the third the *Stag*, in 1770: four more were coppered in 1776, nine in 1777, and in the course of the three following years the whole British Navy was coppered—an event which may be considered as forming an important era in the naval annals of this country.

Some few years after copper sheathing became general. It was discovered that through the connection of the copper sheathing with the iron bolts in the bottom, and the pintles in the rudder, oxidation had taken place to a great extent; and from careful examination it was discovered, that within a period of three or four years the iron fastenings were injured so much as to render the ships unfit to be sent on foreign service. A mixture of pitch and tar, called soft stuff, was put over the ends of the bolts, and other ironwork in the bottom, to prevent the contact of the two metals; but this entirely failed in protecting the iron. The injury to the fastenings assuming such a formidable aspect, the Navy Board contemplated, in 1783, discontinuing copper sheathing, but a suggestion of the use of bolts of mixed metal instead of iron for fastenings for the lower parts of the ships was approved of and adopted for a time; but before the end of that year, copper, instead of iron bolts, were ordered to be used in all the ships.

The Reports made by the officers of the several dockyards in 1797, as shewn by the Papers of the late Sir William Bentham, state that the sheathing in some cases answered admirably well, while in others the very reverse was the case; but they considered that the copper which was then used was not so good as had been previously used, and recommended the adoption of pure copper nails, the heads of which were to be flatter, so that they might set closer.

Several experiments were made from 1806 to 1808 with soft rolled and hard rolled copper, and the report of the officers in 1808 stated that there was very little difference between the two. In 1808 a recommendation was made, by a Mr. Bennett, to use the sheathing without its being pickled. This was tried by the Portsmouth officers and reported on unfavourably. The same experiment was, however, repeated in 1832 on H.M.S. *Prince Regent*, and in 1833 on H M.S. *Sultan*, with very marked disadvantage.

It will appear then, that it is little more than a century since copper was first employed as sheathing in the Royal Navy. A few years only served to prove its utility and render the use of it general. A few years more served to shew that, exposed to the action of sea water, copper was liable to a rate of wear that had not been contemplated. The history of copper sheathing as applied to the navy, shews that instances of want of durability occasioned strong dissatisfaction not many years after its use became general; and also that great durability was by no means an unusual characteristic of some of the copper sheathing thus early employed. But it is not necessary here to trace the changes which took place in the character of copper supplied to the navy so long ago, as the experience of a later date will suffice to illustrate all that need be said on the comparative wear of copper sheathing, the causes which operate most powerfully to its destruction, and the means likely to increase its durability.

Sir Wm. Bentham, in 1803, in consequence of the great expense incurred by the Board in the re-manufacture of old copper sheathing, recommended the erection of metal mills in Portsmouth Dockyard, which recommendation was carried out about the year 1805. The quality of the metal was not only improved by this change, but it also effected a great saving. The manufacturers charged £42 per ton, or $4\frac{1}{2}d.$ per pound, for the re-manufacture of the old sheathing; but as soon as the Government metal mills were at work the cost was estimated at $1\frac{1}{2}d.$ per pound. This induced the manufacturers to offer to reduce their price to $2\frac{1}{2}d.$ per pound. The sheathing for the Royal Navy was manufactured at Portsmouth until new mills were erected at Chatham Yard, in 1847.

In 1833, in obedience to an Order of the House of Commons, the supervisor of metals was directed to prepare an account of the cost of re-manufacturing old copper sheathing at the metal mills at Portsmouth Dockyard. It was then shewn that the cost was only £8 0*s.* $10\frac{1}{2}d.$ per ton, or ·86th of a penny per lb. An immense annual saving had therefore been made by the Government up to this time by the adoption of Sir W. Bentham's recommendation; and some of the best specimens of sheathing were produced during the first twenty years of the establishment of that factory. Previous to the erection of the mills in Portsmouth Dockyard the copper sheathing was purchased by the Government in a state ready for use, but afterwards it was refined and rolled at their own mills. From the termination of the war in 1815 till 1832 the copper

manufactured into sheathing in that establishment was old copper, no new copper having been purchased within that time for the use of the Royal Navy. About this time two important changes were made in that department; first, new copper, manufactured partly from British and partly from foreign ores, was purchased; and secondly, the management of the mills passed into new hands. The fact of two changes having been made at the same time has given rise to some perplexity as to the cause of a subsequent result, *viz.*, that of a more rapid wear of copper sheathing.

In the latter part of the year 1823, the Board of Admiralty sought the advice of the President and Council of the Royal Society, as to the best mode of manufacturing copper sheathing, or of preserving it whilst in use from the corrosive effects of oxidation. Sir Humphrey Davy undertook the investigation; and, as in order to determine what conditions of copper were requisite to its durability in sea water it was necessary to ascertain to what action the waste in the metal was owing, he proceeded first to examine the chemical changes which took place in sea water whilst a strip of copper was immersed in it. The phenomena which that experiment presented formed the basis of a course of reasoning that resulted in a discovery of the means by which copper sheathing might be protected from the destructive action of sea water. Sir H. Davy had already ascertained that chemical attractions might be exalted, modified, or destroyed by changes in the electrical state of bodies; and, by a consideration of the changes that he witnessed both in the copper and the water which had been in contact, he arrived at the conclusion that, as copper was but "weakly positive" in the electro-chemical scale, and that it could act upon sea water only when in a positive state, if it could be rendered slightly negative it would not be susceptible to corrosion in that fluid. His experiments fully established the truth of this supposition; but what was very remarkable, was the relatively small amount of positive metal that sufficed to protect the copper. A piece of zinc not larger than a pea, or the point of a small iron nail, was found fully adequate to preserve 40 or 50 square inches of copper, in whatever part of the copper it might be placed, whether at the top, bottom, or in the middle of the sheet: neither did it matter whether the copper was straight, bent, or made into coils. And where the connection between the different pieces of copper was completed by wires or thin filaments $\frac{1}{40}$ or $\frac{1}{50}$ part of an inch in diameter, the effect was the same; every side, every surface, every particle of the copper remained bright, whilst the iron or the zinc was corroded.

The principle having been fully established that the waste of copper sheathing was the result of electro-chemical action, it had next to be ascertained what proportion of negative metal would protect the copper from the destructive action of sea water. This was determined by another series of experiments, of which the following were the

results:—When the metallic protector was from $\frac{1}{20}$ to $\frac{1}{100}$ of the surface of the copper, there was no corrosion or decay: with smaller quantities, such as from $\frac{1}{200}$ to $\frac{1}{400}$, the copper underwent a loss of weight, which was greater in proportion as the protector was smaller; and as a proof of the universality of the principle, it was found that even $\frac{1}{1000}$ part of cast iron saved a certain proportion of the copper. In the course of these experiments it was proved that cast iron, a substance which is cheaper than zinc, and much more easily procured, was likewise equally fitted for the protection of the copper, except in sulphurous waters. It lasts longer than malleable iron or zinc, and the plumbaginous substance which is left by the action of sea water upon it, retains the original form of the iron, and does not impede the electrical action of the remaining metal.

On the 7th June, 1824, the Navy Board issued an order that the surface of the protectors in contact should be $\frac{1}{80}$th part of the surface of the copper. The form in which the protectors were applied was in bars 6 inches wide at their base, 3 inches in thickness at their centre, and, in outward form, represented the segment of an extended circle placed horizontally amidships, about 3 feet below the water line.

Dr. Paris states that, after a trial of the protectors which lasted several weeks, the surface of the copper sheathing became coated with carbonate of lime and magnesia, and that under such circumstances weed adhered to the coatings, and marine insects collected upon them; but that when the proportion of cast-iron or zinc was below $\frac{1}{150}$, the electrical power of the copper being less negative, no such deposition occurred, and that although the surface had undergone a slight degree of solution it remained perfectly clean. He considered this a fact of great importance, as it pointed out the *limits of protection*, and made the application of a very small quantity of the oxidable metal more advantageous than that of a large quantity.

Whilst, however, the agency to which the principal waste of copper sheathing was owing was thus satisfactorily determined, Sir H. Davy directed his attention still further to the causes of destruction in copper sheathing, as he had been led to suppose there must be a mechanical as well as a chemical action contributing to the general effect; and from the experience he acquired during his voyage to Denmark and Norway, he concluded that on the most exposed part of the ship, and in the most rapid course, the loss owing to mechanical action was to that resulting from chemical action, in the proportion of nearly 2 to 4·55. I shall have occasion to refer to this point hereafter, as much of this action depends upon the character of the copper under trial. The value of these discoveries can hardly be over estimated, as they have constituted the most important indications in all subsequent inquiries. It is known that the application of Sir H. Davy's protectors led to the rapid fouling of the bottoms of ships by the adhesion

of weeds and zoophytes; and that, in consequence of this unexpected disadvantage, they were abandoned at an early stage in the experience of protection. This abandonment of a principle because of a concomitant difficulty certainly does not meet with the approval of scientific men. But whether there was propriety or not in such a course, the result of it has been that no effectual means have since been employed for the protection of copper sheathing; nor until within the last few years was anything done towards investigating the destruction of sheathing. This may be attributed to the loss of a man, who, although not unexposed to the jealousies and comments of different parties, had the full confidence of the Navy Board.

The health of Sir H. Davy was such as to prevent his further investigations of this subject; or the same powerful mind that suggested and carried out the requirements of the Admiralty, *viz.*, the preservation of the copper, would very soon have overcome the fouling. Others following out his beautiful design, and at the same time taking advantage of the results of his experiments with perfect and imperfect conductors, have to a certain degree realized his unborn views of regulating protectors by the partial interruption of the current; for he pointed to this fact in his experiments with different numbers of sheets of paper, which have led to the interposing of a porous material—canvas, wood, or earthenware—between the positive and negative pair; whilst protection has been afforded, and, at the same time, a clean surface preserved. These proposals, however, emanated without the acknowledged reputation of a Davy: hence they have not met with any encouragement except in Sweden.

Dr. Bompas proposed in July, 1831, to apply protectors of mixed metal to the copper, thus modifying, and endeavouring to diminish the excessive action of Sir H. Davy's protectors. He also proposed shifting protectors, to be placed and removed at pleasure. This plan was tried at Portsmouth on the *Fair Rosamond*, in May, 1833: she proceeded to the West Coast of Africa, and in February, 1837, the Portsmouth officers reported one-third of the copper worn off. The remainder was very thin and had lost one-third of its original weight. Shifting protectors were also proposed for trial by Professor Daniel in 1840, by myself in 1841, by Mr. Prideaux in 1843, and by Dr. Clanny in 1848. These suggestions had special reference to vessels intended for the Coast of Africa.

Some experiments have been carried out in the chemical department, on what have been termed "Regulating Protectors." These, whilst affording protection to the copper, are not supposed to promote the growth of weeds and shell-fish on the bottoms of ships as is done by fixed and permanent protectors. A piece of cloth or thin wood was interposed between the positive metal—zinc or iron—and the negative copper, in order to impede or curb the current action, by which means the oxides of metals or matters formed in the sea water, were not so readily transmitted to the negative plate. The

results have shewn that where the conductor was in direct contact, no loss of copper has taken place; but, on the contrary, an increase of weight, due to oxides attached firmly to the plates, has been the effect. With the protectors having wood placed between them and the copper a certain amount of loss took place; but with those which had canvas interposed, the loss was much less than where the copper had been unprotected altogether.

While alluding to the subject of protection for sheathing, I may be allowed to state that one mode of slight protection which I referred to in my report on this subject in May, 1854, appears to have been overlooked. With reference to the nails for fastening the paper on the bottom, I observed, that the substitution of metal nails for iron, not only greatly increased the expense for this service, but also removed a slight protective agent in the preservation of the sheathing, as the iron, aided by the acid of the vegetable tar, would protect the copper; and the destruction of the nails would be, of course, no object after the sheathing was applied. Most of the extreme durable coppers were put on before the substitution of metal for iron nails took place, although some of the early examples of bad wearing copper were also treated in the same way. Some persons have questioned the extent of the protective action of the protectors, but it must be understood that those of the size used on Sir H. Davy's principle will not protect badly manufactured copper, as local electro-chemical action may be set up in several parts of the same sheet.

The late Admiral Sir Edward Owen considered that the iron cables and the iron paddle-wheels of steamers acted like Davy's Protectors, and caused the copper to foul. He was perfectly correct with reference to the paddle-wheels as regards the fouling; and the decay of the spurs of the paddle-wheels by galvanic action in contact with the copper sheathing was very great. That removed from the *Elfin* was nearly decayed through its mass; and that of H.M.S. *Penelope* was reduced from its original size—$4\frac{1}{2}$ inches, to $2\frac{1}{2}$ inches. Some of the incrustation—the coraline matter from 5 to 8 inches in length—with which H.M.S. *Geyser* was entirely covered, will shew the state of her copper when she was docked at Portsmouth.

For several years after, efforts were commenced by those in the Service to ascertain the cause of the increased wear of copper sheathing: the various conditions of its use were supposed to have more to do with that wear than the intrinsic state of the metal. This opinion was also entertained by the late supervisor of metals, who stated that the superior durability of copper sheathing must be sought elsewhere than in its composition; and that it must be sought less in the properties of the copper than in the conditions of its use. This has been refuted by many facts: first, general experience did not support it: secondly, there had not been such changes in the conditions of its use as to justify

the supposition; and, thirdly, practical facts were directly opposed to that opinion. The placing of different descriptions of copper in the same conditions has shewn that they are subject to variations of wear to a remarkable extent in accordance with what might be expected from the physical condition of the metal.

In all the attempts which have been made to improve the protection of copper sheathing, it has been practically admitted that from whatever cause the deterioration may have resulted, the excess of wear is a consequence of its increased susceptibility to electro-chemical and chemical action. The accidental conditions of wear which have frequently been the object of attention, were not thought of before the quality of the sheathing was impaired.

During the time in which, as already mentioned, there was no new copper purchased for the Navy, the old copper was constantly being re-manufactured; and it was this, as well as the new copper which had been previously purchased, that had the great durability which efforts have since failed at imitating. As has been proved, the most durable copper sheathing may lose its durability in the process of re-manufacture. The two following illustrations shew that copper which has been very durable while on ships, when removed and re-manufactured, has been of a very different character. The very durable sheathing which was removed from the *Ajax* in 1845 (it having lost only 7 ounces per sheet in sixteen years), was afterwards re-manufactured and placed on the *Orestes* in 1848, and lost from 14 ounces to 23 ounces per sheet in four and a half years; also, that removed from the *Northumberland* and placed on the *Volcano* after being re-manufactured, lost from 9 ounces to $10\frac{3}{4}$ ounces in three years. It was shewn that the wear of this copper was increased from seven to eleven times by the process of re-manufacture.

The late Mr. Owen, supervisor of metals, considered that the acid of vegetable tar had much to do with the destruction of copper on ships' bottoms, and also that it was the cause of the rapid deterioration at the water line of ships newly coppered. But it has been proved that the same rapid destruction of copper sheathing existed where coal tar was used for the paper and the bottoms.

The water in different climates has been understood to produce very different degrees of effect on the copper sheathing of ships. No doubt an exaggerated estimate has been formed of the effect due to particular waters in destroying the sheathing; but general experience seems to concur as to the destructive effects of the water in some parts on the coast of Africa, and other stations to which our ships are sent. The late Professor Daniel investigated this subject, and in May, 1841, delivered a highly interesting lecture before the members of the Royal Institution, "on the Chemical "Action of Water on the Copper of Ships." The substance of this lecture was afterwards published.

Various suppositions have been put forward to account for the extraordinary change which has taken place of late years in the durability of copper sheathing. Some have had regard to the mode of refining and manufacture—some to the methods of using it, and some again to the description of ores that are used—the idea being that the foreign ores which have been used for some years past have contained impurities which the processes of refining do not remove, and which, remaining in the metal, are sufficient to account for the short duration of the sheathing. The fact that the ordinary new cake copper manufactured into sheets was less durable than that formerly used, supported the supposition that the mixing of British and foreign ores had the effect of damaging the quality of the copper. In addition to the opinion of some of the most eminent smelters in South Wales, the late supervisor of metals, reasoning upon the fact that no new copper had been bought into the Service from 1815 to 1832, endeavoured to establish the correctness of his views by a table of ships examined by himself. This table shewed that distinct lines of deterioration appeared to commence first about the year 1829 and again in 1833; 1829 being the date when new copper was bought, and 1833 the date when British ores were first mixed with those from Peru, Chili, and other countries, and which contained impurities not found to the same extent in the Cornish ores. He stated that, "From an examination of all the ships which had had their copper stripped "or examined in Devonport yard from July, 1843, to December, 1845, the following "result was obtained:—On 15 ships, the copper of which bore date prior to 1832-3, "the average loss per sheet per annum did not amount to one ounce, whilst on the same "number of ships with copper bearing date subsequent to 1833, the average loss per "sheet per annum exceeded 4 ounces, leading to the conclusion that the deterioration "of the quality of the copper commenced 1832-3."

The necessity of ascertaining the nature of the ore, as well as how far the particular kind of ore used for copper sheathing might affect its quality, had been so frequently urged, that the Admiralty Board sanctioned experiments in this direction; and at the latter end of 1844, fifty tons of tough cake copper was obtained from each of the firms of Messrs. Grenfell & Co., and Messrs. Williams & Co., these gentlemen consenting to its being prepared in the presence of the late supervisor of metals. These experiments, although carried out with such great pains in the process of smelting and refining the copper—the produce of English ores *only*, did not afford a result such as would justify the supposition that the cause of deterioration consisted either wholly or principally in the use of foreign ores.

Various analyses have from time to time been made to solve the cause, and not unfrequently they have been isolated from any experiment either synthetical or physical.

The first which I have on record, was in July, 1790, and was by William Higgins, of Soho: he reported to the Navy Board that by various trials of the copper he found it alloyed with $2\frac{1}{2}$ per cent. of lead, with antimony and tin in much smaller quantities; and that a loss of 3 to 4 per cent. was unavoidable in reducing it to pure copper. He also stated that copper so alloyed was apt to be injured in repeated annealing, especially with sea coal fuel, and that it was much more easily penetrated and corroded by the marine salts of sea water than pure copper. Further analysis was made by Sir Humphrey Davy, in 1823, by Professor Daniels, in 1839, by Mr. Prideaux, in 1840, and afterwards by Mr. Philips and Dr. Faraday. Mr. Prideaux, at the recommendation of the Committee on Metals, subsequently made another analysis with about twenty-five specimens. Although analyses were made by so many authorities, yet the Committee on Metals in their Report attached more importance to the conditions of the use of the metal, and quoted the opinion of Dr. Faraday on the subject of analysis, notwithstanding he was unsuccessful in determining by analysis alone the cause of the irregularity and rapid wear of copper sheathing. Dr. Faraday, in October, 1830, in reply to the Navy Board, who had forwarded him small specimens of copper sheathing which had been procured from various private manufactories and from Portsmouth Metal Mills for analysis, expressed his distinct opinion that analysis would give no useful indication, and that as far as his experience went, the fitness of the copper did not depend upon its comparative purity or impurity, but upon some point at present unknown or not understood. "This opinion, therefore," he says, "I give in place of any report upon the "samples of copper you sent me."

With respect to the great and important object of discovering what it is that enables some coppers to resist the action of sea water, whilst other copper placed in exactly similar circumstances is powerfully corroded, I have experiments in hand; but whether I shall ever be able to make that discovery which was refused to the genius of Davy, and has resisted all the attempts of interested capitalists, is a matter of great doubt. From the experience I have gained in the course of a great number of analyses of copper which has been either intentionally or accidentally alloyed with small quantities of foreign elements, and combined with other practical forms of experiment upon such copper, I am enabled to corroborate fully that opinion as regards analysis unaided by practical experiment. Any investigation under such circumstances must however be made at a disadvantage, and the result of it rendered doubtful; because it appears vain to determine by analysis alone what constitutes the durability of copper sheathing. There are some elements which have been commonly regarded as injurious to the sheathing, but which, when within given proportions, are known to be beneficial; and there are other elements that have been but little considered, but which, nevertheless,

produce by their presence a great effect on the character of the copper as adapted for sheathing. Again, certain elements used as alloys are beneficial when restricted to certain limits, but which if used in excess would be highly detrimental.

One important condition regarding alloys, is that they should be present in a *metallic* state, and not in the form of an *oxide.* Metallic alloys within the following proportions improve the sheathing:—

Silver from $\frac{1}{500}$ to $\frac{1}{1000}$	Zinc from $\frac{1}{50}$ to $\frac{1}{300}$
Iron „ $\frac{1}{300}$ „ $\frac{1}{500}$	Tin „ $\frac{1}{100}$ „ $\frac{1}{300}$

Potassium in the proportion of $\frac{1}{300}$ will soften copper; whilst carbon from $\frac{1}{200}$ to $\frac{1}{500}$ will harden it and render it adamantine if in due proportion and combination. A larger proportion of the latter element will not combine with copper *chemically*, but only *mechanically;* and in this combination it is very injurious.

In the most durable copper sheathing I have examined, I have found some element or elements in substitution of oxygen and sulphur; these, when existing in copper, cause it to present the greatest difficulties to obtaining uniformity of wear of the metal, whilst the finer the copper, and the more uniform its texture, the more slowly and uniformly does corrosion take place, irrespective of the minutest differences in its chemical constitution. Most of the durable coppers which have worn with great regularity and smoothness, have been of uniform texture throughout, and of good specific gravity; but they seldom consist of pure copper. The durable sheathing manufactured between 1815 and 1830 was not characterised by purity. It contained portions of tin, zinc, lead, iron, silver, gold, phosphorus, cadmium, each of these substances being appropriate as an alloy; whilst the quantity contained in the sheathing was only so much as would improve its durability. The very rapid wear of copper sheathing appears also to be less influenced by the presence of foreign substances than by the manufacture of the metal.

The descriptions of copper sheathing remarkably deficient in durability are generally found to contain either large portions of negative metal in spots or patches, or various oxides, either of which contribute to the rapidity of decomposition — the result of electro-chemical action: at the same time, the purest copper is often found to decay very rapidly.

The foreign substances, in the form of scoria, are often nearly removed from the copper in the process of re-smelting, and the durability of such copper is not unfrequently less after that process than it was before; other elements of a more destructive character, such as oxygen, carbon, silicon, and aluminium having entered into the metal. Much injury is likely to arise from the presence of lead (important as it is as a flux), if the poling is not carried on long enough, and at a temperature sufficiently high to

facilitate its removal. In such case it is in a state of mixture, and not in the definite form of an alloy; hence electro-chemical action is set up.

A suggestion was made by a Mr. Moyle, one of the managers of the Morfa Copper Works, at Swansea, relative to the production of a more durable sheathing from the hard copper which is separated from the soft at a certain process of the smelting. In 1846, thirty tons of this copper was refined with unusual care under the personal superintendence of Mr. Owen, at Swansea; but in the refining, much less lead was used than usual. This copper, when rolled into sheathing, was marked, and placed on ships with other copper to present fair conditions of comparison. The reports on the wear of that made at Swansea, and which was placed on ten ships, was, with two exceptions, that it had lost less than the several kinds with which it was tested.

In June, 1850, shortly before the death of the late Mr. Owen, supervisor of metals, I received three different samples of copper sheathing made from the same batch or bath of copper, but taken at different periods of ladling. I was requested to carry out a series of experiments, the object of which was to ascertain whether the quality of the copper, as to its suitableness for sheathing, differed sensibly in the different stages of the ladling of the same bath. The results indicated such dissimilarity in the rate of wear of the metal at the several stages of ladling as to account for frequent variations in the wear, not only in the sheathing of the same date, but in the different parts of the same sheet; and were indicative of very great benefit to be derived from a continuance of investigations and experiments in this direction. The production of good copper from the bottoms is contrary to the idea formed by many persons. Mr. Prideaux, in alluding to this kind of copper, states,—"In the smelting works the demand for selected "copper has greatly increased: one-third of the whole refining is said to be thus "disposed of (in great part for Muntz's yellow metal), and the cake generally sold, is "proportionately deteriorated by its abstraction. The deterioration does not appear from "an analysis to be of uniform or generally similar materials, the hards and drainings of "the refining being most probably unequally commixed, and producing the unevenness "of surface above noted."

In October, 1847, the Admiralty purchased of Messrs. Schneider & Co. some of the copper obtained by Napier's process. Some of this was rolled hard and some soft. Another portion was refined in the metal mills at Chatham, and a part rolled hard and a part soft. It was thus found to be very pure, but very soft, and in each case wore very rapidly. Generally, the result was different to that expected, as the soft rolled in many instances was equally, and in some cases, more durable than the hard.

Instances have occurred in the Navy, of the very rapid destruction of sheathing about the water-line of ships, whilst other portions have not suffered wear in proportion.

It has been supposed by some who have given opinions on the copper question, that such excessive wear resulted simply from atmospheric influences, without implying a fault in the condition of the copper itself. This opinion does not, however, appear to be verified; but it rather seems that the rapid wear at the water-line is strictly relative to the general quality of the copper, and that that copper which will best resist the action of sea water will also best resist the combined influence of air, water, and friction. This action is especially due to the metal being exposed alternately to the agency of the air and water: the air yields its oxygen freely to bad moistened copper, as some kinds have worn through to the wood in seven, and nine months; but this was not so with some of the durable coppers removed from the water-line, as instanced in the *Stirling Castle* and *Pitt*. At the water-line of the *Pitt* the copper had been subjected to but little loss, the worst sheet having sustained only about 19 ounces loss in twenty years. This ship lay in Portsmouth harbour, where it is common for ships with some kinds of copper of recent manufacture about the water-line, to suffer as great a loss in about twenty months.

The result of analysis having shewn the presence of certain bodies, and absence of others, in good wearing copper, a series of alloys was prepared in the chemical department at Portsmouth which has been subjected to the action of sea water for years, both in a state of ingots, and also rolled out into thin sheets, and the loss has been recorded at several periods.

The Zinc Sheathing Company has stated in advertisements that the standard for the duration of copper sheathing is four years, that of the yellow metal five years, and that of zinc six years. Such a standard could have regard only to the inferior copper, and not to the real capability of that metal for wear as sheathing, as it has been ascertained by many facts to exceed by far the present reputed standard, and as also shewn by a table of 130 durable coppers all of which had lasted from ten to sixty years. The well-known ship *Victory*, when receiving a thorough repair in 1857, after having been repaired and fresh caulked, was sheathed with the old copper that had been removed from her bottom, although it had been in wear thirty-four years.

From the table just alluded to, it appeared that copper was removed from two Norwegian ships, the *Prince Gustave* and the *Sleipner*. The former ship was built in England, and sheathed with copper which was so bad that it was necessary to remove the whole of it in less than three years. Norwegian copper was then put on, and when I received my specimen of it in 1852, the report stated that when examined in 1848 it had been on about twelve years, and was in excellent order as well as being very clean. On the *Sleipner* the copper was worn uniformly and very little, after having been on a

period of thirteen years. It was not removed from any defect in the copper, but only to enable the ship to be re-caulked and the wood work to be repaired.

In February, 1851, I received a memorandum from the Board of Admiralty to the effect that Swedish copper was not used in Sweden for sheathing in consequence of the presence of iron in that metal; and that English copper was invariably used for sheathing in that country. To this I submitted that a pecuniary consideration caused the use of English copper for sheathing in Sweden, as Swedish copper was, in England, worth £3 per ton more than that of the best English copper for manufacturing purposes; and so highly was it valued in France, that it was with difficulty obtained in the English market.

The loss sustained in copper sheathing has always been considered a serious expense; but the protection of the bottom from destruction by the torpedo, and fouling by weeds and animalculæ, fully compensates for that expense. Experiments have as yet failed to show that any of the improved kinds of sheathing are superior or equal to ordinary wearing copper. Eighteen vessels in Her Majesty's service have been sheathed with Muntz's yellow metal, and from the reports it has appeared to wear well. Some few sheets have proved brittle, but on the whole the results have been equal to what had been expected from it. But for the purposes of the Government, copper should be of that durable character that all ships sheathed and lying in the harbour should be in such a state as to require nothing but cleaning before proceeding to sea.

Hall's patent copper is on trial on sixteen ships. One only as yet has been examined—the *Alert*—which was sheathed September, 1856: in December, 1857, it was removed. It was then found to be eaten through in some places, the loss being greater than with the ordinary Chatham copper, a sample of which was on the same ship, and the loss on which was $5\frac{1}{2}$ ounces per sheet. A very limited trial has been made with copper prepared with phosphorus, which seemed to be a desirable addition; but whether due to the presence of the phosphorus, or to that substance producing a species of refining by ejecting all oxygen, remains to be proved. It will be seen by the results of the experiments with phosphorized copper sheathing that it is desirable to apply chemical agents to improve the copper used for sheathing.

Dr. Percy, of the Government School of Mines, and one of the most talented metallurgical operators, at the meeting of the British Association, at Swansea, in 1848, through alluding to the effects of certain foreign bodies upon copper, such as sulphur, phosphorus, &c., induced Colonel Sir H. James, of the Royal Engineers, at that time associated with Portsmouth Dockyard, to express a desire to test some specimens, with which Dr. Percy had furnished him, in sea water. The results of these experiments with copper containing phosphorus were so satisfactory that Sir H. James obtained

permission from the Admiralty to have it tried. The trial was made, although on a limited scale, and the report was in favour of the copper containing phosphorus.

The durability of copper sheathing of former manufacture establishes the fact that it is not from anything essential to the metal. Whatever difference, therefore, there is between the conditions of such copper, and that more recently manufactured, is a condition of manufacture and not one essential to the metal; hence it may be expected that, when the modes of manufacture which gave durability to such sheathing are repeated, the like durability will again be realized.

This Paper has already extended beyond the limits I proposed: I must therefore leave the interesting point so frequently alluded to—the action of sheathing-nails on copper—until another time. I may on some future occasion have an opportunity of reading Papers on copper alloys and brasses used for shipbuilding purposes, and the effect of the different kinds of metal on sheathing. The evidence and experiments on the nail question alone are very extensive, and would make this Paper much too long. I may state that from all the evidence before us it must be possible to manufacture durable copper sheathing.

There are fifteen or sixteen different species of cuprous ores in the different parts of the earth unlike one another in their chemical constitution. In most of them the metal is united with sulphur, iron, zinc, antimony, lead, arsenic, silver and gold: these ores in some instances pass through ten or twelve different processes, the final one being of deoxidizing by wood, coal, coke or charcoal. If this operation be improperly performed the copper will contain either oxide of copper or charcoal, chemically combined, or mechanically diffused throughout the mass.

The investigation of Dr. Matthieson into the causes effecting the conductivity of copper for electricity, in reference to its suitability for the submarine telegraph, &c., have shewn that very small additions of foreign substances to pure copper impair or lower its conducting power.

It is quite the reverse, however, as regards the durability of copper for sheathing purposes. Very small portions of foreign matters in their elementary state, brought into combination with copper, add materially to its suitableness for this use. Analysis, as well as practical experiment has shewn that perfectly pure copper, whatever its condition may be, is unsuited for sheathing, it being more readily acted on by air and sea water; and I have reason to believe that the small quantity of oxide of iron in Swedish copper may render it very superior for planishing, and for vessels required for high temperatures. It has been fully proved that fusion, sometimes termed refining, produces very great changes in the durability for sheathing.

In bad wearing sheathing, manufactured from new cake copper, the irregularity may be accounted for by the metal not having been in a state of fusion long enough, or not having been poled sufficiently to get rid of the metalloids, or the oxides and other matters contained in the re-manufactured copper. Decision upon the suitableness of copper, with regard to its refinement, as judged by the time the process has occupied, is quite fallacious. In one furnace in my department the same quantity and quality of copper will on some days require from one-third to two-thirds longer time to run than on others, the natural blast only being used. This difference is in consequence of the state of the atmosphere.

Experiments have been made upon the densities of copper of the same quality by casting ingots at different periods of time; those having been longest in a high state of fusion have exceeded those removed previously from the same crucible. There is nothing strange in this when we consider the part which heat plays in all uniform chemical combinations. Continued intense heat will not, without oxygen, remove many metallic bases in combination with copper; and the great difference in the character of copper poled with green wood instead of dry, would point to hydrogen as the important agent in causing the homogeneous state and density of the copper. This important operation in copper refining is little understood, and therefore little regarded.

The application of chemistry has done much towards determining the requisites for an efficient composition for sheathing. It has done enough to render it extremely probable that its resources properly applied may produce all that is necessary to compensate for the loss of superior skill in the manufacture. The late Sir H. De la Beche pointed to chemistry as the branch of science to which this subject legitimately belongs; and the most useful opinions that have been obtained on this subject have led to the same conclusion. I may also quote the opinions of two very much respected and experienced master shipwrights, William Edye, Esq., late of Devonport Dockyard, and the late J. I. Fincham of Portsmouth Dockyard. When called on by the Admiralty for his observations on the Report of the Committee on Metals, Mr. Edye stated that he believed it was the general opinion that copper was not so well manufactured as it had formerly been; this opinion arose from the scovy, or clouded appearance on the surface of the sheets, and from the frequent finding of small holes not larger than the points of small pins in them. This was not the case with former manufacture. The late Mr. Fincham stated:—"I would suggest that chemical supervision is necessary in the manu-
"facture where so many causes appear greatly to affect its state; such as the temperature,
"fuel, fluxes and alloys. In this view I am borne out by the usage of the late master
"of the metal mills of this yard, Mr. Vernon, who was very successful in the manu-
"facture of copper sheathing; and who had the superintendence of the metal mills

"until 1831. He was particularly careful in making assays, and in conducting the "processes with reference to the appearance the metal exhibited in the assays. The "analysis made by Dr. Playfair and Mr. Prideaux, of Napier's copper, favours this view "of the want of uniformity in the copper used for sheathing ships; in the one instance "the analysis gives iron, and in the other it gives iron and lead. I am satisfied from this "that we ought to have more frequent assays of the copper during its manufacture."

J. Prideaux, Esq., metallurgist, states in his report,—"That the effectual refining and "commixture are at the command of the Admiralty, in their own works; also the "restricting of the sheathing to the upper part of the pool, by which they could produce "a select copper of their own; one, most probably, equal to the old durable sheathing. "The admixture of zinc and tin requires skill and judgment to render the metal "perfectly homogeneous, without which the destructive voltaic reaction would occur. "With such perfect commixtures and combinations a maximum of durability might be "attained, requiring only regulation to prevent fouling; and rendering the sheathing, "most probably, superior to the average of any period since the introduction of copper "for that purpose."

Although in the earliest preparation of sheathing for the Navy the application of chemistry to the process of its manufacture was not well understood, yet what it was deficient of in science was in a great measure supplied by practical skill in refining and purifying the metal. And further, whilst the durable sheathing manufactured in those times was often alloyed with foreign elements, the more complete fusion to which the metal was subjected in the furnace brought the alloys into such a state of combination with the copper as to render it beneficial.

Refining and alloying are entirely chemical matters, and the durability of sheathing depends on the perfection of these operations; but without analysis of the copper before, during, and after the manufacture, the different physical conditions brought about either by chemical process, or otherwise, will fail to give that insight into the subject which it is so desirable to have. Again, the nail experiments, numbering upwards of one hundred, and which have been in progress for years, have proved that the irregular wear and loss sustained on sheathing is due in a much greater ratio to chemical than to electro-chemical action.

In conclusion, I will quote the opinion of Dr. Percy, on the subject. He says:— "With regard to the determination of the composition of the copper employed as "sheathing, it cannot be expected that any results of much practical value will be "obtained except by very expert chemical analysists."

I will now only observe that in whatever respect the advantages of improving the copper sheathing may be looked at, primarily, public economy is the ultimate point

towards which it necessarily tends. The value of the copper on the ships' bottoms, and its annual cost would scarcely be credited by any one not conversant with such matters; and until chemical supervision is combined with the process of manufacture, nothing definite can be insured; and chance and irregularity must continue.

DISCUSSION.

The CHAIRMAN, (J. Scott Russell, Esq., Vice-President): I am sure you will all agree with me that this is a valuable Paper, and worthy of a place in our *Transactions*, from its containing all that is known—and I think I should say all that is not known—about the various kinds of copper; which various kinds of copper do not apppear to present to analysis any chemical differences. I happen to know myself, from other sources, that this difficulty is a very serious one. It does appear very much as we find it in the case of steel. We find in the examination of steel and homogeneous iron, and all the substances which we have between the extreme of steel and the extreme of soft iron—we find, I say, a great number of substances in which no chemical difference can be found, but which have different mechanical properties. So it appears, that between one pure copper and another pure copper there are differences. Whether they originate in the manufacture, or whether they get in later, or where they come from, is a most important subject; but I am told that in the ordinary processes of the manufacture of copper, the cream of the copper is not left for sheathing, but goes for something else; and although that which remains and forms the material for sheathing is pure copper, and cannot be refused either on account of adulteration or chemical defect, yet it is not copper that is fit for sheathing, the copper that is fit for sheathing being creamed off for other purposes, and for which a higher price is obtained. As this is a very important subject, we ought to be very pleased that it should have fallen into the hands of a gentleman who has long, as I know, been famous for the application of chemical knowledge to every improvement in the bottoms of vessels; and who has also applied his skill to the keeping clean of the bottoms of iron ships. If he can succeed in that which he proposes he will confer a still greater benefit upon the public. I have therefore great pleasure in presenting your thanks to Mr. Hay for this excellent Paper. If any gentleman has any questions to put upon this subject, I think I may undertake to say, that the author of the Paper will have great pleasure in answering them.

Mr. BARNABY, M.I.N.A.: There is one practical difficulty with regard to wooden ships armour-cased. The armour is carried 5 or 6 feet below the water, and the copper extends from the keel to just beneath the armour. Now it appears from the experiments of Sir Humphrey Davy, that when the iron was not in contact with the copper it protected the copper. I should like to know Mr. Hay's opinion on this point. In sheathing these ships, if you have 2 or 3 feet between the bottom of the iron plating and the copper sheathing, will there be galvanic action? Are we to expect, though we leave 2 or 3 feet of wood between, that the copper will be prevented from being oxidized; and that we shall not have a foul bottom?

Mr. HAY, Assoc. I.N.A.: I should say that if you make use of the patent waterproof glue on the wood between the copper and the iron, you might prevent galvanic action; but most wood, especially in sea water, is a very perfect conductor between the two metals, and one which answers the purpose of fine filaments of metal. I think the subject should be taken up by chemists who should work at it for twenty or

twenty-five years before you attempt to sheath your armour-plated vessels. I recently saw an article with regard to the condition of *La Gloire*, and I wrote to the Minister of Marine to get information on the subject. After waiting a fortnight, I received a reply stating that it was contrary to their rules to give any scientific information on such a subject. I wrote as a scientific man, and stated how I was travelling in this direction; that I was labouring to point out the right direction to go in, not merely for my own country, but for the world at large. Under those circumstances I did expect that a report would have been made shewing what had been done. No doubt I could have got the information if I had gone to work clandestinely, but I thought it more honourable, as a scientific man, and as a representative of a Government establishment, to apply to the fountain-head, and endeavour to obtain the information which I desired. I think we give other Governments a great deal of information.

Mr. GEORGE PEACOCK, Assoc. I.N.A.: I have made the subject of the formation of copper sheathing my study for the last thirty-five years, and as a practical man, and a shipowner, I have taken a great deal of trouble to endeavour to find out some means of preserving the copper from the rapid wear which arises from causes such as have been explained in the Paper just read. With respect to pure copper, the Chairman has stated that the cream of the metal is not used for sheathing, because it can be sold at a higher price for other purposes. From my experience, as a shipmaster, I think pure copper was used in the first instance. We know that the action of salt water upon pure copper caused by the friction of the ship passing through the water, is to put it in a positive electrical state. A gradual exfoliation of the metal then goes on, and in course of time it becomes as thin as a piece of tissue paper; and a metal which is not quite pure becomes in a honeycomb condition.

Mr. HAY: I have some specimens of that with me.

Mr. PEACOCK: With respect to the friction which causes the positive state of electricity that the copper assumes, I believe it is the means of keeping the sheathing clean, because, as was proved by Sir Humphrey Davy's protectors, when the copper is in a negative state it gets foul; and the presence of any iron or zinc in the neighbourhood of the copper, I know from experience, has the effect of making the copper remarkably foul. As to bringing the copper near the armour plating below the water, no doubt the copper would be rendered negatively electrical; and it would not only get fouler than an iron bottom, but all the parts below the water line would be rapidly destroyed. I believe that is now the case with regard to *La Gloire*. The whole of her plates below the water-line are in such a state that they must be renewed before many years elapse.

The CHAIRMAN: Have you any direct information on the subject on which Mr. Hay may rely?

Mr. PEACOCK: I should not like to give my authority, but I believe I may say with certainty that the plates of *La Gloire* are very seriously deteriorated, and her copper is in the state which Sir Morton Peto described in the House of Commons; no less than 40 tons of oysters, barnacles, and weeds having been taken from her bottom when put into dock at Toulon.

The CHAIRMAN: They may be forty reasons why Mr. Hay did not get the information he wanted.

Mr. PEACOCK: The subject is a very interesting one as far as I am personally concerned. I am connected with upwards of 10,000 tons of wooden shipping with copper bottoms, and which run between this country and the West coast of South America, and the East Indies; and we find that by using a certain preparation on the copper, it is not only kept clean, but the copper is kept from deterioration from year to year. On stripping one of the vessels, we found that the copper had been deteriorated only to the

extent of 5 per cent. of the original copper that was put on. It was free from that roughness which takes place when the preparation is not put on.

The CHAIRMAN: Is the preparation you speak of applicable to iron as well as to copper?

Mr. PEACOCK: Not the same preparation: there is another preparation for iron; but for copper I can safely say that the one in question is very effectual. It was applied to the *Ariadne* on the West India station, and she has been docked only once since, and that was for cleaning.

The CHAIRMAN: Has the preparation to be often renewed?

Mr. PEACOCK: Once in twelve months, because the action is partly mechanical and partly chemical. It is advisable that the preparation should be renewed every twelve or fifteen months.

Mr. HAY: It is too late for me to trespass any further upon your attention, otherwise I should have had much pleasure in stating a few more practical points in connection with copper. In former times the manufacturers of copper had no dockyard stores to provide with copper, and the manufacture was accordingly carried on by the rule of thumb. It was carefully watched till the metal assumed the proper colour, but the metal was never run till the process was complete. Copper requires a certain time to expel the mixture of injurious substances, and without proper care in the manipulation, we cannot get the quality of copper which we want for these purposes.

ON IRON-CLAD SEA-GOING SHIELD-SHIPS.*

By Capt. Cowper P. Coles, R.N., Assoc. I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 27th, 1863, the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

It is with extreme diffidence that I appear before this meeting on the present occasion to answer the attack that was made yesterday, upon my principle of arming and protecting guns and their crews in ships of war; and when you consider that I am a man who has passed the best part of his life at sea, and that I am quite unaccustomed to address meetings of any description, much less such a meeting as this, composed, as it is, of men of such mark and weight, I am sure that I may calculate on your kindly making allowance for the unusual position in which I am placed.

Yesterday, you heard a most clever Paper read by Mr. Reed, in which he explained the advantages supposed to be gained by the adoption of his plans, and the disadvantages that would result from the adoption of my system. I do not propose to follow Mr. Reed throughout the whole of the subject which he has discussed, but will simply confine myself to explaining the relative advantages and disadvantages of the shield principle, and to meeting the objections which he has raised. But before proceeding further, I beg to express my thanks to the Right Honorable Chairman, and to the meeting, and especially to those gentlemen who have Papers to read, for the great generosity which has been shewn me in the precedence that has been given to my remarks.

The ship shewn in Fig. 1, Plate III., has been drawn to shew the principle upon which I propose to mast my shield-ships; and let me explain at the outset, that she is intended *solely* to illustrate my principle, and not as the exact counterpart of the vessel that I would build as a war-ship.

Yesterday, Mr. Reed entered into a comparison of the *Defence* with an imaginary shield-ship, taking his data from a publication in the *Mechanics' Magazine*, of the 27th of February. That article referred solely to the comparison of the masts, sails,

* Received May 13th, 1863.

and spread of canvas of the *Defence*, and a ship of the same tonnage on my system; and the table to which he referred, although it contained a *general* statement of the weight of broadside of these two vessels, was founded only upon exact calculations in its details of masting and spread of canvas. I have the less difficulty in making this admission, because the same journal, on the preceding page, contains a Paper by me on iron-clad ships, in which I entered fully into the comparison of a real shield-ship designed by the Controller's Department, with vessels of different classes built by the same constructors on the broadside principle. I think I might have expected that in any reference to my published opinions, a Paper which I had published and devoted entirely to the subject in dispute, would have been selected instead of one in which it was noticed only casually.

I will now proceed to explain,—first, my mode of masting; and secondly, my mode of constructing and arming iron-clad ships. My principle of masting ships may briefly be described as the substitution of rigid iron tubes for the lower rigging, thus forming with the masts a tripod. It will be easily understood, by reference to Figs. 1 and 2, Plate III., which represent a shield-ship of nearly the same tonnage as the *Defence;* but although there is no increase of weight aloft, the shield-ship spreads 32,456 square feet of canvas, whilst the *Defence* spreads only 22,251 square feet.

Fig. 3, Plate IV., represents the shield-ship prepared for action. The topgallant mast and yards having been struck, and stowed between decks (the mode of doing which I shall defer describing to a future occasion), nothing is left aloft but the iron tripod lower masts, with their long mast heads or topmasts. The lower or topsail yards are of iron, fitted with Cunningham's, or ordinary topsails; the former of which, besides having other advantages, can be either rolled up or set without exposing a man, the halliards and sheets being led down the hollow masts between decks. It is well known that a ship, steadied by her topsails, would have a great advantage in the precision of fire. The following advantages, I contemplate, would arise from the adoption of tripod masts:—

1,—They would be much stronger and more durable than masts secured according to the present mode by numerous perishable shrouds. They are keyed to each deck (see Fig. 4), which also shews their relative strength. This mast, indeed, is secured as when heaving a ship down, *viz.*, by sheers; and it is well known what an enormous strain a mast so secured will bear. It has to be remembered that, with rope shrouds, and stays, a mast is only sustained on one side (unless the vessel is dead before the wind), but the tripod masts will receive support on all sides; for whilst one portion of the structure is in tension the other is in compression, so that each portion of the structure would be doing its work towards resisting any strain that might be brought

against it, whether from pitching, rolling, or any other cause. And I conclude it will be impossible for a ship so masted to lose her lower masts from the effects of the elements.

2,—From there being no lower rigging the great training powers of the shield are not interfered with.

3,—There being no lower stays, the yards can be braced nearly fore and aft, or in a line with the keel, thus enabling a ship so rigged to set her square sails when under steam; whilst with the present rig she would be obliged to keep them furled.

4,—They would afford additional means of ventilation in all weathers, forming three ventilating tubes in lieu of one.

5,—From their great strength, ships blockading or on other service would be better enabled to keep the sea in heavy weather, and maintain their stations; and would better withstand the shock received when striking the shore, or when giving another ship the stem.

6,—They afford great power of defence against boarders by means of the mast platforms for the use of small arms, the men being protected by wet hammocks, as shewn at B, Fig. 3. The fire which would be brought upon the deck from them, and the shields which are not only shields for great guns but are also rifle-towers, would, I think, prevent boarders making any lodgment on the deck, or attempting the much-talked-of "wedging the shield." It also has to be remembered that if wedges were forced in by boarders from above, they could be easily driven up from below; and the men above would be exposed to fire, whilst those below would be under cover.

7,—They will, as already stated, give a greater spread of canvas with less weight than the ordinary masts with rigging. Further, all sails and yards on each mast being of the same size, the spare ones will answer in any case.

8,—The sails are so balanced as to enable the ship to steer and work well—two points of difficulty in the present rig, which are frequently the cause of serious complaints. The distance between each mast in my proposed rig being governed by the yards not locking when braced up on different tacks, instead of the mizen and mainmasts being placed close together, whilst a great distance is left between the main and foremast as in the ordinary mode, I am enabled to place the centre of effort well before the centre of flotation, so that the ship will work well, particularly in wearing; which is very far from being the case with the iron-cased ships rigged in the usual unhandy manner. One great cause of the defective working powers of these ships is, in my belief, chiefly attributable to their mainmast being placed too far aft; another is to be found in their not being able to set a sufficient quantity of canvas *in proportion to their tonnage.* This

latter is a very grave defect, for it renders an iron ship incapable in many cases of keeping her position in a fleet when under sail, and at a time when it may perhaps be of great importance that as little fuel should be burnt as possible. We had an expensive instance of this defect in the *Defence*, during the Baltic cruise. My plan has another advantage, none of the yards which I propose being more than 91 feet long. We lately heard of the *Warrior's* mainyard being carried away: now, I am almost afraid to say the number of these gigantic yards of the present day—yards, some 105 feet long—which I have known carried away, and that, not from any want of skill or seamanship, but simply from the weakness consequent on their great length; and I am assured by officers in the Iron Fleet that, during their last cruise to Madeira, when attempting to wear in the line-of-battle ships under sail, from the time some of them took going round, they were seven miles apart when re-formed on the other tack, and this was mainly owing to the rig. I am also assured that the large ships could not wear in heavy weather.

9,—The topsail yards can be lowered down on the lower yards in action, and the two lashed together ; so that if one is shot away it will be kept aloft by the other.

10,—The last, though not the least, advantage to be derived from the adoption of these tripod masts would be the great saving which would be effected in the expense annually incurred through the enormous deterioration in the rigging of those men-of-war which it is thought necessary according to the present system to keep ready for service in the steam reserve. Ships with these tripod masts would always be comparatively ready for sea, and whilst their perishable sails, and running rigging remained stowed away below, nothing would be exposed to the mercy of the elements but their iron masts and yards. Jacob's ladders are provided for the men to go aloft.

Important as my tripod rig may appear for men-of-war, I believe it will be found equally important for our mercantile marine; where great advantage will arise from the saving of wear and tear of rigging, of manual labour, and of loss of life and property.

It is well known that being dismasted is one of the most frequent causes of ships being lost or deserted, and that the annual loss of life and property is something fearful to contemplate; and even when a dismasted ship is picked up and saved by another, her cargo is frequently ruined from the water which has poured into her whilst lying unmanageable in the trough of the sea. It has also to be considered that our clipper ships, after a run to China, often require a thorough outfit, if not an entire new set of lower rigging.

Change of climate and temperature often endanger the masts of ships from the effect produced upon the rigging, whilst change of climate would have no effect upon these iron tubular tripod masts; and I think we may reasonably expect that they would last as long as any first-class iron ship they might be placed in.

It may be said that it is necessary for a mast to have some play, and that these tripod lower masts would be too rigid. That argument might hold good with wooden masts, but it is well known that if an iron mast had play, the rivets would work loose and eventually destroy the masts; so that the more rigid an iron mast can be made the more secure and durable it will be.

The next question to be considered is the mode of working and protecting heavy guns in revolving shields on turntables placed in the centre of the vessel, instead of working them through portholes at the side.

The advantages which I consider will be derived from the former principle are as follows: 1,—The power of carrying the heaviest ordnance that can be manufactured, whereas ships with broadside ports are limited to the present 68 or 110-pounders: 2,—The throwing of a far heavier broadside in proportion to tonnage: 3,—Rapidity and precision of fire, and an extent of training not to be gained by any other method: 4,—Great speed, less beam being required: 5,—Better sea-going vessels, from the weights being more centred: 6,—Lighter draught of water: 7,—Shorter and handier vessels for easy turning, docking, &c.: 8,—Great spread of canvas and saving of fuel, with the chances of the fouling of the screw being reduced to the minimum from there being no lower rigging: 9,—Good ventilation, and great comfort to the crew: 10,—Greater defensive power: And lastly, the cost of these ships, particularly when we have the reconstruction of our entire navy in view.

To commence, I will refer to my comparisons before alluded to, and published in the *Mechanics' Magazine.*

Mr. Reed appears to think my comparisons unfair. But I have taken the actual guns which these ships have on board, and those for which my shields have been ordered to be prepared for the ships building.

In comparing the destructive powers of these ships' broadsides, it has to be remembered that the mere weight of metal if taken alone, would convey but a small idea of the effect they would produce, as a few heavy projectiles from large guns might destroy a ship, *which would receive little or no injury from a broadside of the same weight of metal made up of a number of shot of a smaller size.* But setting aside the great advantages of heavy shot, it is now known that shells, under favourable circumstances, can be made to penetrate iron plates $4\frac{1}{2}$ inches and $5\frac{1}{2}$ inches thick. These shells, to be effective, must contain large bursting charges, and be of great size and weight—two conditions which necessitate the employment of guns too heavy to be used in ships with broadside ports. In making the following comparisons, I trust it will be understood that I have no desire to expose the defects of any particular ship, but that I am solely influenced by an anxious wish to add my mite towards arriving at a just conclusion upon

this most important subject. Plate IV, which is drawn to scale, will enable us to compare and contrast the two principles, *viz.*, of working guns, protected by armour, in broadside fixed batteries, and in revolving shields.

I will commence with the *Defence*. She throws a broadside of 560 lbs., and is 3,720 tons. The *Prince Albert* shield-ship throws a broadside of 1,120 lbs., and is 2,529 tons. She has the power of fighting half her guns on either side, thus having two broadsides of 560 lbs. each, or being equal to two *Defences*, although the *Prince Albert* is 1,191 tons smaller than the *Defence*. This then, being the case, I am at a loss to know how it can be said that the shield-ship when engaged even on both sides, would be at a disadvantage as compared with a broadside ship; for it is obvious that in weight of broadside alone when fighting with both sides, the *Prince Albert* would be equal to two *Defences*. But there is another most important point when fighting both sides, and which appears also to have escaped notice. It is, that broadside ships, even with their present large crews, can only fight every other gun when engaged on both sides; and if this be true of the 68-pounders, and Armstrong's 110-pounders, what could they do with guns of a heavier calibre? Thus the *Defence's* broadside is reduced to $\frac{560}{2} = 280$ lbs., when fighting both sides; whilst the shield-ship, working her guns by mechanical appliances, still continues to throw two broadsides of 560 lbs. each. But besides these destructive powers of the *Prince Albert*, she draws 5 feet 8 inches less water, and is wholly clad with $4\frac{1}{2}$-inch iron, instead of being partially clad as the *Defence* is with the two ends, the rudder, stern-post, and screw unprotected.

I will now compare the *Prince Albert* and *Valiant*. The *Prince Albert* throws 26 lbs. less in her broadside; but she is 1,381 tons smaller, draws 5 feet 2 inches less water, and is wholly protected, whilst the *Valiant* is only partially clad. I next take the *Prince Albert* and *Warrior*. The *Prince Albert* throws a broadside of 246 lbs. more than the *Warrior*; she is 3,430 tons less, draws 6 feet 2 inches less water, and is wholly clad, while the *Warrior* is only partially so.

I come now to the *Favorite*; but as Mr. Reed objects to the armaments I have given, perhaps he will kindly tell me what armament she is intended to carry in one broadside. [Mr. Reed here informed Capt. Coles that she was to carry a broadside of four 110-pounders.] We then have a broadside of 440 lbs. in the *Favorite*, while the *Prince Albert* throws a broadside of 1,120 lbs., being a difference in favour of the *Prince Albert* of 680 lbs., or more than double, although she is only 343 tons larger, but draws 1 foot 11 inches less water.

I will next take the *Royal Sovereign*. Her armament will consist of five 300-pounders, throwing a broadside of 1,500 lbs. This ship being a conversion of a three-decker into a floating battery, I will not compare her to any particular ship; but she

throws a heavier broadside than any other iron-cased ship we are building. She draws 2 feet 5 inches less water than the *Warrior*, and is 2,146 tons smaller. Her speed is estimated at 12½ knots, and she is wholly cased with 5½-inch iron; and with 1-inch iron on her decks, while none of the others have more than ½-inch.

Mr. Reed said I had taken the *Defence* as being the least favourable ship that could be compared to the shield-ship; but he ignored altogether the other three ships which I had compared, and forgot to mention the great difference of tonnage, draught of water, &c., in which it will be seen that the *Prince Albert*, shield-ship, has such an advantage (see Plate IV). But this is not all; for Mr. Reed even admits that the 150lb. spherical shot did almost as much damage as the 300-pounder Armstrong. In my taking the mere aggregate weight of a ship's broadside, I have not given that advantage of destructive powers which is due to the heavier ordnance in my shields; for it is well known that a 150-pounder spherical shot does more damage to an iron ship than six 110-pounders rifled Armstrong guns, even supposing those shot to hit nearly in the same spot, which in action is improbable if not impossible.

But I have given Mr. Reed his own armament in the *Favorite*, and I still find that the *Prince Albert* throws more than double her broadside: it must also be remembered that the *Prince Albert* is doubly as strong as the *Favorite*, and that the *Prince Albert's* armour plating goes 4 feet below the water-line, whilst the *Favorite's* only goes 3 feet. The *Prince Albert* has 4½-inch plates over 18 inches of backing, half an inch inner skin, and 10½-inch frame, similar to the *Warrior;* whereas the *Favorite* has only 18 inches of backing behind the 4½-inch, *and no inner skin or frames;* besides which she has no iron on her upper deck, and is, therefore, likely to be set on fire by any molten iron shell.

Mr. Reed says,—"I should like to ask whether any sloop's side was ever made as "strong and impregnable as that of a line-of-battle ship?" I reply that the *Prince Albert's is*, but the *Favorite's* certainly *is not.*

I have endeavoured fairly and impartially to compare these different ships, and I must now leave it to be considered whether I, or Mr. Reed, has made the fairest comparison, he having taken a nominal ship, one not in existence, and given the *Defence* an imaginary broadside; whereas I have taken the ships built and building with the actual guns carried and ordered to be carried by them.

It may be said that the shield-ships I have compared are not sea-going ships; but a small portion of the great difference of tonnage would be ample to allow for masting and sea-going qualities. I must leave it to you to judge whether I have not proved my first assertion, *viz.*, that my vessels carry a far heavier broadside in proportion to their tonnage, rather than Mr. Reed has proved that "The broadside ship is three times "as powerful." But Mr. Reed, when making this statement, must evidently have been

ignorant of the fact (and I can easily forgive it, for I do not suppose he ever saw a gun fired at sea), that the Armstrong 110-pounder is a much less effective gun than a 68-pounder, and that these iron-cased broadside ships, even with their present large crews, can only fight every other gun when engaged on both sides.

Mr. Reed also complained of my having conspicuously noticed and printed in my tables "wholly" and "partially clad." I am sorry he should take exception to this; but as it happens to be so, I do not see why I should not point it out. And I would wish to call particular attention to the fact, that the shield ship is not only of much less tonnage and has a heavier broadside, but that she is *wholly protected*, whereas the other three iron ships, the *Defence*, *Valiant*, and *Warrior*, with which she is compared are only *partially plated.*

Mr. Reed again says, "Wholly armour-plated shield-ships, fit for sea-going service, "cannot possibly be built of small dimensions. If Captain Coles and Admiral Halsted "will not object to following in the track of the *Enterprise* design and adopt partial "plating, they will be able to approach much more nearly to their object." Now, it will be seen at page 46, Vol. II. of the *Transactions*, that in February, 1861, at this Institution, I proposed the very belt the *Enterprise* has, in the following words:—"The "battery or fighting part of the ship is kept quite distinct from the other portion of the "ship, the men living in the fore end and the officers in the after end of the vessel. "These ends are built of the ordinary scantling of a first-class iron ship; but an iron "band of $4\frac{1}{2}$-inch iron, extending 4 feet below and 4 feet above the water-line, is carried "round bow and stern, taking in the rudder-head, which is protected by a $4\frac{1}{2}$-inch iron "cylinder, with slot-ways cut for the tiller." Instead then of my following suit, I must be allowed to reverse the order of things, and I need not point out that Mr. Reed has followed in *my* track. And I am still more surprised at Mr. Reed claiming this belt, as I published a letter, calling attention to my having proposed it long before his was heard of; and not only this, but a cupola vessel with a belt was actually drawn out by the Controller's department in 1861. I am at a loss to know what portion of Mr. Reed's vessels he claims as his own idea. Fig. 1, Plate V, represents the vessel that I would propose for foreign service to replace our wooden frigates. She would be 3,700 tons, 285 feet long, 52 feet beam, of 24 feet draught of water, and have a speed of about 13 knots: she would carry two shields with four 300-pounders, throwing a broadside of 1,200 lbs. The central part of the vessel, sufficient to protect the shields and engine, would be wholly plated, and the ends of the vessel protected by a belt as before described. She would have ample room for the accommodation of the officers and men, with good ventilation from numerous portholes, &c.

However, as Mr. Reed does not seem satisfied with any displacement unless

actually his own, by way of making a more complete comparison of my system and the broadside system, I will take a vessel of exactly the same tonnage, form, and construction as the *Favorite*, and by way of distinguishing the two ships, I will call my ship the *Naughty Child*. The only difference between the *Favorite* and the *Naughty Child* is, that the latter vessel is fitted with two revolving shields in lieu of one square box in the centre (see Figs. 2 and 3, Plate V.) Mr. Reed has already chosen his armament for the *Favorite*, *viz*:—Four 110-pounders, throwing a broadside of 440 lbs. Now I find that this square box and armament weighs 285 tons, which when worked up into shields would give the *Naughty Child* two shields, carrying three 300-pounders, or equal to a broadside of 900 lbs. Thus, with the same weights, the decks being the same height out of water, *viz.*, 7 feet 8 inches, I throw double the weight of broadside. May I ask then, why should these two vessels not be equally good sea-going vessels, and have equally good ventilation, for they have the same amount of openings on the upper deck? The *Naughty Child* would have her shields, which, when she was battened down in a gale of wind, would act as hatchways with 5-feet combings to keep the sea out. It will be seen that the deck of the *Naughty Child* is 7 feet 8 inches out of water, and the gun 10 feet. Moreover, the elevation and position of the port-hole, in the shield system, is attended by another advantage, *viz.*, their transfer from the sides to the centre of the vessel. This is illustrated by Fig. 1, Plate VI., which shows a shield-ship inclined at a sufficient angle to bring her gunwale to the water, and yet carrying her guns and port some feet above it. Fig. 2, Plate VI., shows the *Favorite* of exactly the same height out of the water, inclined at the same angle, and yet burying her ports and guns in the sea.

It cannot be necessary to add a word by way of enforcing the lesson taught by this illustration. It should be remarked, however, that the same causes which tend to disable the fighting of the guns in the *Favorite*, while those in the *Naughty Child* remain perfectly fit for action, tend also, in a less degree, to give the latter superior steadiness when the two ships are rolling through less angles of inclination under ordinary circumstances. The less a gun is moved about the more accurate is its practice; and it is easy to see that the guns in the *Favorite* are moved through much smaller spaces than those in the *Naughty Child*. This is an advantage not to be slighted in these days, when such costly efforts are made to improve our artillery practice, and fighting powers at sea.

We now come to the arc of training. It will be seen from Plate V. that the shield-guns in the *Naughty Child* have a range of from 310° to 154°, whilst those in the *Favorite* have only a range in the broadside of 56°; and to bring a gun within 9° of the keel, either ahead or astern, it must be transported into the ports cut in the thwart-ship bulkheads. Even then I do not see how they are to be worked, for there is not sufficient room between the gun and the ship's side. However, transporting a gun, particularly in a sea way, is not

an easy matter, and in action, might prove fatal to the vessel having to do so; whilst the shield-ship, when on the bow or quarter, would be playing away with the whole of her broadside on the *Favorite's* square box. Another great objection to this square box is the great area which it presents for the enemy to aim at, and concentrate his energies on; whereas the areas of the two shields are much less, and would oblige the enemy to divide his fire and attention. At the same time the entire side of the *Naughty Child*, from stem to stern, would be made one solid unbroken mass of framing and plating, perfectly proof to all ordinary shot and shell; while, on the other hand, the side of every iron-plated ship with portholes, such as those in the *Favorite*, is impaired by the presence of numerous portholes, every one of which not only weakens the structure of the side, but also gives ready entrance to the enemy's shot and shell upon the fighting deck in the crowded box of guns, where a single shell would spread panic and confusion.

Now, considering the great superiority of weight of broadside, the arc of training, and several other advantages which I have pointed out, as possessed by the *Naughty Child* over the *Favorite*, if they met at sea, I think I may be justified in saying that the *Favorite* would stand no chance, or that the odds would be greatly against her in an action.

But there is one more point for which, while I touch upon it for one moment, I must beg your patience. Mr. Reed talks of ranging alongside these shield-ships, boarding them, and wedging the shield. Now, this is a point of warfare which I fear Mr. Reed cannot have studied. In the first place, does Mr. Reed know that as long as vessels have their motive power and helms at command, either party can, by a few spokes of the helm, prevent boarding? But, on the other hand, suppose they do succeed in boarding the shield-ship, she would then train her foremost guns aft, and her aftermost guns forward, and sweep the whole deck with grape and canister, independently of the riflemen from the top of her shields, and from the platform in the masts. I do not hesitate to say that, at such a time, it would be almost impossible to board these vessels, much more so to wedge the shields. But now, let us see if we get alongside Mr. Reed's ship and board her, what we can do. He has a square tower extending to each side of the ship, with an area on the top of 3,128 square feet, which is elevated about 6 feet above the deck. Why, I have only to throw a few men on the top of this castle, and they have possession of the ship. There is not a gun nor a loophole for a rifleman to command it; whilst men on the top of this box would command the whole upper deck of the ship fore and aft, shooting down every one who attempted to come up the hatchways. Again, the funnel passing through this castle is a weak point, for a hole could easily be made in it with a maul, and a shell thrown down would destroy the boilers. Indeed, I can see no better device for taking this vessel than this square box in the centre.

Mr. Reed refers to the *Monitor*, and in general terms would have people suppose that my vessels are of the same description. But I think it will be seen from the description which I have given that there can be no comparison between them and the *Monitor* which was not 2 feet out of the water, the *Naughty Child's* deck being 7 feet 8 inches.

Mr. Reed says,—"Here then at the very outset, all hope of a small sea-going turret "ship, wholly armour-plated, to steam at a fair speed, is at once annihilated." I think the comparison of the *Naughty Child* and Mr. Reed's *Favorite* has already put this assertion of his own on one side; and a proportionate advantage would arise from the *Naughty Child* having a revolving shield in lieu of a fixed battery. Mr. Reed again says,—"We must also drop for the present, at any rate, the notion that we can fire "more rapidly from a turret than from the broadside." He appears to think that the rapidity of fire from the shield in the *Trusty*, was in consequence of the gun being a breech-loader; but I must explain that it was in consequence of the shield being trained while the gun was loading, the captain of the gun looking over the top, and never losing sight of the object. At a broadside port the object cannot be kept on or got on until the gun has been loaded and run out. Does Mr. Reed know that, as a rule, muzzle-loaders are more rapid in firing than breech-loaders, when you come to heavy guns? One hundred and six rounds were fired from the gun in the shield on board the *Trusty*, and we beat the gun in the broadside port on an average of 3 rounds to 2.

I shall be happy to bow to Mr. Reed as an authority with regard to working out the displacement of a ship; but I must be excused if I do not submit to his authority as a gunner.

As much has been said about wedging the shield or jamming it, I must tell you that the shield in the *Trusty* was fired at with 110-pounders and 68-pounders at the short distance of two hundred yards; sixty-nine rounds were fired, and it was hit forty-four times, but it was never stopped working; and you can imagine the little damage that was done to it, when after this severe test, we fired six rounds from it with as much precision and rapidity as before.

From these experiments, and from what we have heard of the American *Monitors*, which are much inferior to what we are now building, I think I have every right to put the greatest confidence in this point as regards the shields.

Mr. Reed refers to some cupola vessels building in England, and speaks in general disparaging terms of them. But I have every reason to believe that they will fulfil in every point the expectations of their designers and owners. "One," Mr. Reed says, "has armour *only* 3 *feet below the water line*." He must surely have forgotten, when he so pointedly urged this as a defect, that his vessel the *Favorite* also has only 3 feet of

armour below the water; the *Enterprise* is the same, and at her ends has only 1 foot of armour above the water line. Time only will develope the principle of central revolving armaments.

I have endeavoured fairly to show what I consider the advantages; and although the broadside and central armaments have thrown some heavy broadsides at each other, yet I hope it may all be taken in a friendly spirit, with a view to a fair discussion, which is the only effectual means of eliciting the truth. Under this conviction, I have given so much publicity to my views, which I am gratified to find, has, at all events, drawn forth my great opponents; and I may be excused if I say that the broadside port has not proved that it can carry anything like so heavy a broadside in proportion to tonnage as the central revolving shield.

DISCUSSION.

[Before proceeding with the discussion upon the above Paper, the Right Hon. President said he considered it incumbent upon him to take the sense of the Meeting as to the duration of time which the remarks of each person should occupy, there being then four additional Papers to be read and discussed, independently of the discussion which was about to take place, and only a very limited time to do it in. After several opinions had been expressed, it was decided by a majority that each person's remarks should not extend over ten minutes.] The following discussion upon Capt. Coles's Paper then took place:—

Mr. E. J. Reed, Mem. Council, I.N.A., said: I will venture to trespass upon a portion of the time of this meeting, in reply to the remarks of Capt. Coles. I should like to preface my observations by saying that if Capt. Coles has overturned any of the representations I made yesterday concerning the difficulty of building small sea-going shield-ships, he will have gratified no one more than myself, because it was not until I came to close calculations that I found it seemed so difficult as it now appears to me; and in course of my Paper yesterday I simply wished to state the difficulties which I felt to be in the way of the adoption of his plan. I had no desire to put any other obstruction in his way than that which arose out of the matters of fact involved in it. Now, Capt. Coles in the earliest part of his Paper admitted frankly—and I am very glad he did admit it frankly—that the statement published in the *Mechanics' Magazine* as to the power of sea-going shield-ships was a fallacious statement.

Captain Coles: I said it was not altogether true.

Mr. Reed (*continuing*): Capt. Coles asked why I took that ship, and not ships out of his table. I took that ship because it is the only sea-going shield-ship mentioned in the two Papers. I do not think it would be fair to myself to go and take, as Capt. Coles has done to-day, a coast defence vessel, originally designed never to carry a mast at all, and thoroughly incapable of performing sea service in the same way as other ships do perform such service. I do not think it would be fair to select such a ship for my comparison. I took the only public representation concerning a sea-going shield-ship I could find; and if I want a confirmation of the justness of the course I took, I shall find it in the drawings and remarks

which Capt. Coles has placed before you to-day. The only representation of a sea-going shield-ship I had seen was for a ship of certain dimensions. It was to be wholly armour-plated, and to carry four turrets. I asserted that a ship of the given dimensions could only be partially plated, and even then could carry but two turrets. Capt. Coles has put before us to-day a ship of those very dimensions carrying just half the number of guns and turrets,—precisely as I said yesterday.

Now, in reference to the comparison between round shot and elongated shot, Capt. Coles very fairly says, that he took the ships as they are armed. I designed to impute no intentional unfairness to him in the matter. I know he has taken the ships as they stand; but my point is this, that if you do compare round-shot guns with elongated-shot guns you deceive yourselves and everybody else who listens to your statement. What I say is, that in the case of all these ships—and in the case of the *Defence*, my first illustration—they happen to mount 68-pounders; and I can have no better illustration of the force of my own remarks than the circumstance that the Admiralty have thought it fit to put 68-pounder guns into the *Defence* rather than 110-pounders. What better illustration can you have than that fact? They prefer a shot weighing 68 lbs. to one of 110 lbs.; and I say, therefore, it is delusive to take the weight of rifled and round shot, and to mix them up. Capt. Coles gave us in his published Paper, and has given us again to-day, the 300-pounders, and would have us compare them indiscriminately with all other shot. In the exercise of common sense I insist upon comparing round shot with round shot and long-rifled shot with long-rifled shot, whether you have only five or fifty rounds. I have heard nothing at all from Capt. Coles to invalidate at all the soundness of that principle, which I believe to be the true one and the necessary one. In going before the public you will lead persons enormously astray by mixing up round and elongated shot. The one fact, that in the experiments at Shoeburyness the 68-pounder round shot produced about the same effect as the 150-pounder long-shot, is quite sufficient to substantiate that doctrine. Capt. Coles—and I cannot blame him at all, for it is a wise policy of his—hits me hard as to what men can do at sea with guns, and of course he can afford to do that. But I think it is hardly fair to limit the powers of the vessels mentioned in the Papers to one-half of their guns by the drill which has been in use in the Service under former circumstances. There is nothing in the world to prevent these vessels carrying—in fact they are designed to carry—enough men to work the whole of the guns on both sides at a time; and I never intend to throw away one-half of the guns by working only one-half at a time. They can be worked both sides at once. If necessary I will pray the present Board of Admiralty to repeal the drill as regards these ships. With regard to the *Naughty Child*, I cannot say that Capt. Coles could put those two turrets into that ship. I will not deny or admit that, because henceforth, after what we have heard here yesterday and to-day, I will not admit any proposition of any gentleman who is not a naval architect on a naval architectural question. But even assuming that he can do that, then still I say that the *Favorite* has advantages which his does not possess, as you will see in one moment. The *Favorite*, in addition to her 8-feet deck, has a 6-feet bulwark; and, therefore, when that ship is at sea, she is practically a ship nearly twice the height out of the water which the *Naughty Child*—or as I prefer to call her, the *Very Naughty Child*—is. I should like to make several other remarks if I had time. I will just refer to the drawings in Plate VI. You will see that the sea has been very accommodating. It is represented as going most beautifully into the ports of the *Favorite*, but it goes most beautifully down under the guns of the *Naughty Child*. Let me tell you what is a fact. In the *Times* of to-day I see it quoted that the guns of the *Favorite* have been represented by Capt. Coles in another place—I do not know whether the statement that he did so represent them is true or not—but he is said to have stated that the broadside

guns of the *Favorite* could not be used when the ship was rolling at 20°, since the guns would be under the water. Now the fact is, if she were rolling at an angle of 20° the port would still be 1 foot 7 inches above the water line; and yet I am told in the quotation referred to that the guns are to be plunged under the water!

Captain Coles: Seas run up.

Mr. Reed: I do not say that seas do not run up, but they are impartial enough to run up all ships alike, and not to leap up at the ports of one ship and fall down before those of another. I will only add, that I hope the Paper I had the honour to read here yesterday, and the remarks I have had the honour to make now, will have one effect, and if they do, I shall be amply gratified, and everybody will be very much benefited; and that is, that henceforth when gentlemen like Admiral Halsted and Capt. Coles appeal to the public to put pressure upon the Government, their statements shall be unimpeachable, and their facts such as will bear the scientific investigations to which responsible persons will afterwards have to subject them. Otherwise we may get into this anomalous position,—the Board of Admiralty will be used as a weapon to overthrow scientific knowledge, and to goad naval designers into the adoption of plans to which the laws of nature are essentially and unalterably adverse.

Mr. George Skelton: Allow me to say that it is proved nearly every day that the cupola ship is not much of a favourite. I know two instances where a cupola ship has been attacked. In one instance the attack did not last more than twenty-five minutes, and the ship was boarded and taken, with all hands in her. The 300-pounder guns have done for themselves; and it has been shewn that the 68-pounders are much more serviceable for naval purposes, forcing shot through targets at the distance of 1,100 or 1,200 yards.

Rear-Admiral Halsted, Assoc., I.N.A: I think Mr. Scott Russell put the subject yesterday upon a trite and apposite bearing when he said it resolved itself into a question of broadside, and he specially argued it in that view. I throw down this challenge to my friends of the broadside principle,—how can a ship on the proposed plan be defended on both sides with the same extent of fire as the vessel with the central cupola was in September 1861, without using two guns instead of one—I mean, of course, upon every defended point of the broadside? Now, if that be so, then there is a very peculiar importance involved in the point at the present moment. That is to say, in reference to what we have already heard, our ships have yet to be armed—if we have anything more powerful than 68-pounders—by guns which have yet to be made. And if I am right in that respect also, then when our factories get to work to construct the guns with which armour ships have yet to be armed, in order to crack the nuts they may meet with of some description, it is evident that upon the cupola system one-half the guns would be required to arm any given number of ships, where double the number would be required in the other case to arm an equal number of ships on the broadside plan. In other words, upon the broadside plan any ship having to carry five 300-pounders to meet an enemy upon each side would require ten of these new guns; while in the other case, five would be sufficient to completely arm her.

Rear-Admiral Sir Edward Belcher, C.B., Assoc. Mem. Council, I.N.A.: I think it was originally stated by Mr. Scott Russell that those guns are centred on that turntable. They are not centred; and I maintain that if we take one good circular battery, and allow 17 feet for each gun, with a radius of 8½ feet, we divide those guns into three towers, and put them upon the radial basis of that turntable, we have Mr. Scott Russell's proposition of three guns instead of two, the second

tower being lost. I do not yield to Capt. Coles on this question, because I presented to the Duke of Wellington in 1842 a Martello tower with three guns planted upon the radial basis of the turntable. Each gun as it was fired brought its next gun on the same radius and tangent of the circle, where any shots glancing would strike off; the gun was at right angles to the radius, consequently the moment it was fired it was in a condition to be loaded, and the other gun supplied its place. I therefore think that the mode of bringing this gun out on the radial line of the turntable is tending to destroy the whole machinery. These turntables on the railways will bear 50 tons, and if a similar kind are made for our service they will better bear 60 tons for the purpose for which they are intended; and with this advantage, that you have no shock on the turntable, the shock is on the segment, and as the gun is fired the turntable takes up your shock. As regards the *Naughty Child*, I do not like her at all. I have always been taught to believe that as you elongated your mast your vessel became so much more a crank, and if she heeled over was not so easily recoverable. Now, by placing all the weights on the sides, I say you have a good leverage to preserve the stability of the vessel, and there is not much difficulty in recovering her position. It is not so in the other; you have the weights at equidistant points, and the weather gun never passes the perpendicular. On the same principle we keep barometers vertical at sea. The radial lines that would pass over these two guns would give you that easy motion. Now, with the turret and the gun over to leeward, you have to suppose you have got a vessel that would bring back that gun to its position. She is powerful enough to stand all that, and as she rolls with that weight on her, so she will reel back again with a pendulum velocity, giving her an uneasy motion. When a vessel rolled exceedingly—and I have had to deal with vessels of that class—I found that by taking that force out of the bottom, say 96 tons in a vessel of 500 tons, and placing the weights on the extremity—sending up the balance as we call it—I made her crank. She rolled easy, and did not pitch heavy enough to destroy—what I think these vessels would—any of those spars which happened to be injured. As far as these circular masts go, we know what happened, I think, in the *Phœton*, and also in the *Thetis*, under Sir John Phillimore, in 1824. "The vessel gave one sudden pitch," he reported to the Admiralty, "and "the foremast and bowsprit were destroyed." If one of these tripods was shot away, and the vessel pitched and rolled much, it is to be feared she would carry the others after it.

The President: What were the masts of which you speak made of?

Admiral Belcher: They were iron masts, and the ship went out under Sir John Phillimore. I was about to bring before your notice a proposition, not for building fighting ships, but for stopping holes after they had been made: in other words, to prevent a vessel from sinking. It is for constructing vessels with cubical divisions, so that at any time a vessel might be filled with water, and yet it would not have any effect, as at the end of an action all the leaks could be stopped.

Mr. T. S. Prideaux, Assoc. I.N.A.: I should like to give an outline of a vessel I submitted to the Admiralty in 1859. The idea was particularly with reference to iron-plated ships of war. The peculiarity of it was that the ends of the vessel were submerged. Supposing her to be about 300 feet long, she had 50 feet lower deck, and about 80 feet covered fighting deck. I was amazed to see the speed of this vessel in only a slight swell reduced from 9 to 7 knots. But I have now obviated that evil. In the first place, the force of the wind on the sails keeps the vessel steady and prevents the pitching to a very great extent; and in the next place, when there is a good deal of wind to raise the sea, the force of the waves, of course,

drives you more swiftly through the water. I believe that in a few years we shall come to armour-plated vessels; and also that they will have submerged "snouts." The ship which I submitted to the Admiralty had a small submerge paddle at the bow for manœuvring. While at the meeting yesterday I heard it remarked that that was a move of mine in the right direction. It seems to be recognised that in time this plan will come to be generally adopted.

Captain De Horsey, R.N., Assoc. I.N.A.: I wish the question of draught of water was excluded in our designs of ships. Naval actions are not fought in a foot more or less of water. The question of draught of water may produce an inequality in action between ship and ship; but let us not consider draught of water with regard to the weights in the centre of the cupola ship, as compared with the broadside. I think I may simplify the question by putting it in this way—that the effect in rolling of the weight of the gun and cupola, whatever that weight may be, depends upon its distance from the centre of rotation: indeed it varies according to its distance from the centre of rotation. So I believe its velocity in movement, and its momentum will be as the square of the velocity unto its weight. If we measure the distance in the case of the broadside gun, and in the case of the centre of rotation, we find the former less than the latter; and I think you will concur with me that it should not be undervalued, that the leverage of the broadside is very great. I also wish it should not be undervalued, that in the case of the cupola the guns can be fought at an angle which they cannot at the broadside. With regard to American ships as compared with others, I think it must be considered that all the vessels have had thicker turrets than we propose to put into our sea-going vessels. Mr. Reed has said that he proposes his ships should be engaged on both sides. I quite agree with him: the idea which we have hitherto had of fighting only on one side when in action is now obsolete. With the number of guns Mr. Reed has there is no reason why sufficient men should not be able to fight both sides, although perhaps not upon his precise plan; but, as Mr. Scott Russell told us, no doubt the mechanics of the present day will contrive mechanical means for working them. If proper mechanism is found there can be no doubt but that we shall have enough men to fight on both sides.

One word about the rigidity of the rigging. I have always found that the more rigid the masts the better it stands. I think Capt. Coles's plan of tripod masts will answer better than the ordinary rigging which yields to too great an extent. There seems to me to be no valid objection to the rigidity of the mast.

Captain Scott, R.N., Assoc. I.N.A.: I should like to make a few remarks upon the subject of these vessels. You will observe in the cupola vessel, Plate VI, that the gun is some distance from the broadside of the vessel; therefore, to keep her upright you will have the vessel unequally trimmed; and on the other hand there will be a great disadvantage in working round and round. We will suppose her to lose a few plates; and directly she loses them on the side she is engaging her enemy, up will come that side from the water. If you look at the *Naughty Child* with 316 degrees, which I am satisfied myself she cannot bear, —if you observe that the slightest movement in that vessel one way or the other will shut out your objects, you will find that she will not always answer.

Another point as to the cupolas. It has been said that the Americans use the cupolas, and therefore there can be no difficulty about our using them. The Americans have used very small charges in proportion to the weight of the guns. Had they not done so the guns would have required a much larger space for action, and the cupolas would not have been strong enough; but the cupola has absorbed the shock of the concussion. I do not like the idea of riflemen being above the guns as in the tripod mast; and it would be an impossibility for riflemen to lie over their hammocks. The cupola of the *Trusty* was a small one,

difficult to hit, and slanting. These cupolas are upright. The *Trusty* cupola was 40 tons, and it had to resist a 68-pounder shot. Suppose a shot thrown at the same velocity as those were thrown at Shoeburyness the other day, the effect of the blow would be at the least eight or ten times as great as that of a 68-pounder. Therefore, if you have a cupola at all equal to withstand that blow it ought to be eight times the weight of the former cupola. As to changing positions, that may be an advantage; but the fact is, that with your double screw you can easily effect this. A slight movement of the helm would put you in a proper position. I should be quite willing to go into this question did time permit. Last night at the Royal United Service Institution Capt. Coles drew back, and shewed that in his cupola a gun could be fired and that no machinery was required to bring it back. Now I think that the guns when fired would be side by side and not in the centre; so that the space would be circumscribed. You will require exceedingly heavy and large guns, or else your tower will be a great deal too large. The tower will be too great to be put into one of these cupolas, and you will be unable to work it. The difficulty of working heavy guns in the cupola would be much greater than at the broadside, where a gun can be worked with great ease. If you look at the guns in the cupola I think you will agree with me that the two ports would in all probability be soon knocked into one. Captain Coles will no doubt pardon me for alluding to so important a point in these cupolas. In such a vessel as the *Naughty Child*, with two midship batteries, it is clear that the men will not be able to live at all. The ventilation would be worse than that of the blackhole at Calcutta. There is another objection which I brought forward last night, and which Capt. Coles has not answered, namely, that if an enemy dropped molten iron shells upon the covering of the cupola it would pour down into the inside upon the men. I think with regard to the stage or masts that you will be unable to have full play with your guns, whereas in a central broadside ship you will have your guns perfectly clear; you would be always ready, and could not be surprised, which would be a material advantage. Further than this, what is to hinder such vessels as the *Favorite* or *Naughty Child* from having a light gun forward if you choose. There is no reason why we should not have two light howitzers above, so that your vessels can be fully manned. Sir Edward Belcher has shewn the disadvantage of having the guns on one side; and I do not think when you come to this very great weight that you will have much facility for training. Perhaps when we next meet we shall have an opportunity of hearing how these guns have been worked.

Mr. Scott Russell, Vice-President, I.N.A.: I am extremely glad this discussion has taken place, and I will, I think, bring it to one or two points of practical and instructive issue. I am very glad Mr. Reed has disavowed being bound to a particular type of ship, adopted under peculiar circumstances, as a standard according to which he means to construct all ships; and, on the contrary, I am very glad to see and to know that he has very little more prejudice in favour of the *Favorite* principle than in favour of that of the *Naughty Child*, when the *Favorite* is put to her proper purposes, and the *Naughty Child* to hers. I am also glad he informs me that his belief that Capt. Coles's shield ship was very liable to be injured by boarders is a first impression which he does not altogether retain after Capt. Coles's explanation. And having said this much from Mr. Reed to Capt. Coles, allow me to say the following of Mr. Reed's plan against Capt. Coles's. I think it is quite as easy for Mr. Reed to enable his square battery, by rifling, to command the deck fore and aft, as it is by putting the rifles on the edge of the raised stages. Next, I do not think any of us are bound to be either Colcites or Reedites. I do not think the *Favorite* and the *Naughty Child* ought to be pitted against each other at all. I think we ought to see what are the special purposes each is suited for, give each its due, and use each in its place. Now, it appears quite clear to me

that both Mr. Reed and Capt. Coles can carry on a vessel of a given size armour on the water-line, and up to a fixed height above the deck—let us call it five feet—which is common to them both. There is no reason why either of them should not do that. Here we are all agreed. Now, let us go a little further. The next point of difference between them is this,—that having got to the top of the continuous deck, Capt. Coles chooses to put the remainder of his spare weight into two cupolas, with two turntables and four large guns. Mr. Reed chooses to put the remainder of his spare weight into what Capt. Coles not very complimentarily called a square box, but what, if you please, I will call a square battery. And the mere question is, whether the weights are better disposed in Capt. Coles's two cupolas or in Mr. Reed's square battery? Are Capt. Coles's cupolas, turntables, and guns heavier or not than Mr. Reed's battery and guns, taking double the number of guns, if you like, and thus making the broadsides equal in both cases? Well, now, if Mr. Reed's guns in double number and square battery are not heavier than Capt. Coles's shield and two cupolas, and if the guns are of equal weight, there is nothing to choose between them. Next, let me go to height. Capt. Coles requires as much elevation and depression for his guns as Mr. Reed requires for his; and therefore Capt. Coles's battery must have as much height above the continuous line as Mr. Reed's battery, mark you. I think it is not a matter for doubt that Capt. Coles's shield and cupola will weigh more than the sides of the *Favorite*. I think at all events they will not be less. And, therefore, I think we have come to a very narrow question indeed, and the little remaining point of difference is this, whether Mr. Reed can cover the enemy with fewer, or more, or the same number of guns as Capt. Coles. It really comes to that. Capt. Scott made what I thought a sound observation, *viz.*, that there was no reason why in a ship of that size, Mr. Reed should not have crew enough to man eight guns simultaneously. I know no reason; and I think the speciality is this—we have now got such a large vessel and a few guns that there cannot be more objection to carrying a crew capable of working a broadside gun than hitherto. I think, in justice to Mr. Reed, you must allow it that advantage. There is another balancing point between them; it is this—whether Capt. Coles's way of pointing his cupola while the gun is being loaded, and his power to follow his vessel all round the arc of the circle, while his ship is going in any direction he pleases, is not a considerable advantage? I think it is a considerable advantage. On the other hand, I must say, not being a sailor unfortunately, and not a gunner, that I am not an authority on that subject. Nevertheless, I think there is an advantage in that respect in Capt. Coles's cupola.

Now, I believe if we put the *Favorite* and the *Naughty Child* thus together we shall find they are pretty nearly on a par with each other; and I think it a matter of judgment—and of delicate judgment—whether a vessel designed by Mr. Reed to carry eight of those 300-pounders on his broadside plan, or a vessel designed with equal naval architectural skill to carry two of Capt. Coles's cupolas would be the more advantageous. There would not be very much to choose between the one or the other, unless you consider the having of two independent broadsides, which would be a great advantage in favour of Mr. Reed's plan. From this day, then, let us feel that both vessels have points in which they are best, and which nearly counterbalance. The moment you go to a larger number of guns, my strong impression is, that you should give up the cupola and take to the square local battery which Mr. Reed has designed on the larger vessel.

The President: Although the time allotted to this discussion has expired, yet I am sure you will allow me one word: I shall not be ten minutes or five. But I cannot refrain from congratulating the meeting on the great success of our experiment. The ten minutes have not been exceeded in any instance,

and several speeches were considerably within that period. I think you will agree with me that we have had a succession of interesting addresses upon this important subject; and I must congratulate you upon the exemplary good humour with which this discussion has been conducted.

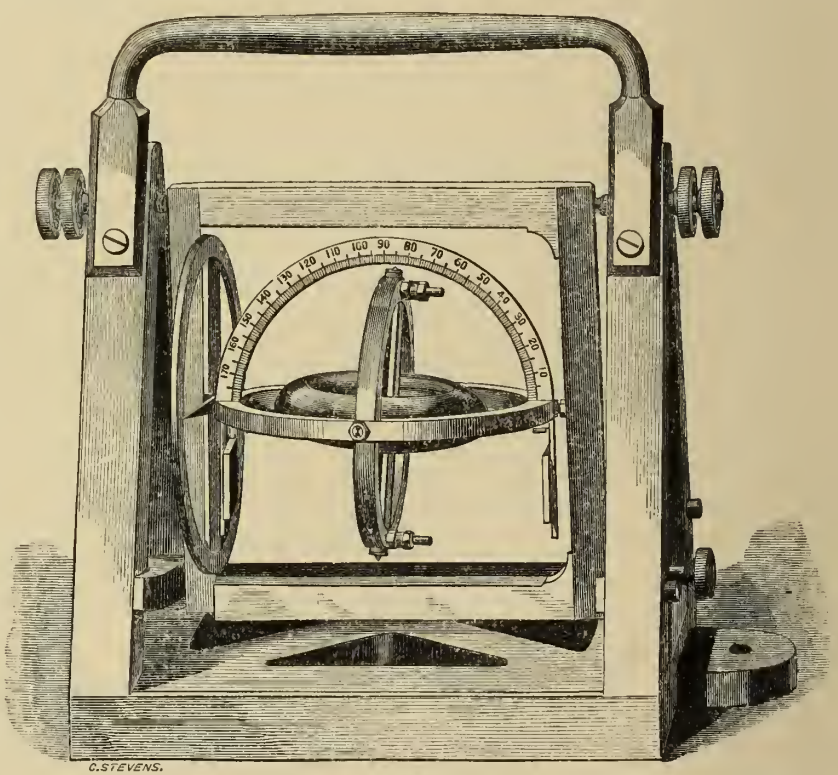
With regard to the question at issue, one cannot fail to appreciate its great national importance; but I should be extremely presumptuous were I to presume to sum up the arguments or pronounce any opinion. I am rather inclined to agree with Mr. Scott Russell, and, in the language of the *Spectator*, to say, "There is a great deal of truth on both sides." I own I think this is one of those cases which we find in most private families, where the favorite is very apt to be the naughty child; and although I do not presume to pronounce any opinion on a question I do not understand, yet I trust I shall not be presumptuous as a landsman if I say I am struck with the tripod masts of Capt. Coles's ship. All of us, whether landsmen or seamen—and it has been my fate, as an amateur, to be at sea a great deal—all of us know that whatever you make your rigging of, it is only the weather rigging that acts, and that the lee rigging is loose. It appears to me that in this particular Capt. Coles's plan presents an obvious advantage. However this may be, it is most gratifying to hear the opinions of a variety of intelligent officers and men, and to see their attention turned to the consideration of subjects of first-class national importance; and I am sure every one here will feel as I feel, that we have listened to this spirited discussion with very great pleasure and considerable instruction.

EXPERIMENTS AT SEA WITH A ROTATORY SHIP-CLINOMETER.*

By Professor C. Piazzi Smyth, F.R.S., Astronomer-Royal of Scotland.

[Read at the Fourth Session of the Institution of Naval Architects, March 27th, 1863; the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

I have endeavoured to give in the following pages some account of the construction and partial trial at sea in 1859 of a rotatory ship-clinometer.



This instrument, which is shewn in the accompanying diagram, and which is based on the principle of free rotation, of which the gyroscope is a well known example, is of a differential character only. It has, therefore, no power of determining absolute inclination, or angular position with reference to horizon or meridian, but gives only the successive differences of position which may occur during a limited period of observation.

In so far, it is inferior to plumb-bobs, levels, fluid-surfaces, and all things depending on gravitation for their zero points; but it is superior to them in these two other features, *viz.*:—

* Received March 7th, 1863.

1st. It is capable of measuring deviations of angular positions in every plane—azimuthal as well as vertical; to which latter, gravitational instruments are confined; and, 2ndly, it is entirely uninfluenced by any of those motions of translation, which, either continuous or frequently reversed, are perpetually taking place in every ship at sea, and are of a nature to mix up with the simple clinometrical movements of all gravitational instruments, completely destroying their value for any exact reference.

Evidently then, if a practical form of the rotatory ship-clinometer can be proved to have been produced, it can hardly fail to yield some valuable and peculiar results when applied to the measurement of the rolling, pitching, and yawing of ships at sea, all of these movements being fully amenable to a difference measuring instrument of this kind, and to no other.

I will now proceed to explain the *construction* of the instrument which is shewn in the diagram. A small fly-wheel, driven by a string as with a gyroscope, is mounted in a gymbol ring, which is again mounted within another such ring; and this last has its pivots in a stout frame, that can be placed on a table so as to have the axial direction of that set of pivots either horizontal or vertical. These latter pivots are furnished with radial arms which point out angular motions on a complete graduated circle fixed to the outside frame; while the pivots of the inner gymbol ring carry pointers to shew its angular motion on a graduated semicircle only, attached across, upon, and at right angles to, the outer gymbol ring.

Now if we place such an instrument on a ship's table, with the pivots of the outer gymbol ring approximately horizontal and parallel with the length of the ship, the plane of that gymbol ring being also nearly horizontal, while the inner one is set at right angles thereto, then, the fly-wheel will find itself with its plane horizontal; and, if spinning quickly under the influence of force previously applied, will maintain that position; indicating all the ship's variations of deviation therefrom, either on the graduated circle, or the semicircle: the "rolling"* element on the former, and the "pitching" on the latter.

In that condition of the instrument, "yawing" will not be shewn, as it is parallel with the then position of the fly-wheel; but if the whole apparatus be turned so as to stand on the table with the pivots of the outer gymbol ring vertical, or nearly so, everything else having a similar relative position to that previously described, then "yawings" will be shewn on the complete graduated circle; and either "rollings" or "pitchings" will be simultaneously shewn on the semicircle, according as that is placed either at right angles to, or parallel with, the length of the ship.

* "Rolling," the motion of the ship from side to side, vertically; "pitching" the same from end to end, and also vertically; and "yawing," the movement in azimuth on a horizontal plane.

In the actual instrument, the frame which carries the pivot-bearings of the outer gymbol ring, has a suspension and fixings inside another frame. But this is only for facilitating the placing of some of the axes nearly horizontal, if the ship's table should be permanently much inclined; also for occasionally allowing the whole instrument, in a quiescent state of the wheel, to be used as a mere gravitational indicator of "rolling" or "pitching;" and has nothing essential to do with regard to the principle of the rotatory apparatus.

We next come to the *adjustments and use* of the instrument. In the former, accurate balancing on each axis, and in two directions at right angles to each other, is the chief point to be attended to. If once well done, and if the instrument itself is firmly made, it need not require touching for months; for the effect of a small error will be merely to produce a very slow processional movement whenever the wheel is in quick rotation; and the effects of that movement can easily be eliminated in a sufficiently approximate manner from any observed angular movement of the ship which will always be, relatively, exceedingly great.

The real difficulty, in fact, which I have met with in using the instrument, lies rather in the complex nature of the phenomena to be observed, *viz.*, the angular motions of a ship at sea, which are nothing less than the motions of a pendulum suffering such a continual state of multifarious disturbance, that it never makes two successive vibrations exactly alike; but, on the contrary, they are often exceedingly different. Frequently, too, when you think that the vibration one way has been completed, there comes a little more in the same direction, instead of the counter motion the other way; and then one does not know which to take as approximately, the vibration, or the roll; or in fact, what to observe and how to call it: and this confusion is made all the more troublesome by the quickness with which the changes succeed each other.

At one time I had a more complicated but complete rotatory ship-clinometer, where there were two revolving wheels, and three graduated arcs; so that all three species of angular disturbances were shewn at one and the same time. But at sea it was soon found that such an instrument could not have its indications registered, unless there were three observers; and as each of these required a writer and a time observer, and had to communicate by sound, without taking their eyes from their respective graduated circles, the confusion was so great and the labour so little lessened, that I turned my attention afterwards to observing only one element at a time, and on a single-wheel instrument, such as I have already described.

The process adopted was something of this sort,—having spun the wheel, and placed it and its mounting in an appropriate position for observing "rollings," I kept my eyes fixed on the movements of the index over the divisions of the graduated circle, from and

after a certain recorded minute and second of time. Whenever the index seemed to have reached the end of an arc of the ship's "rolling," I read off instantly the degree and fraction of a degree it was momentarily standing at, entering it on a paper by my side; and entering similarly, the place of every successive standing still of the index, one under the other, by feel only, for the eyes could not be taken off the index for a moment, until a sufficient number of observations for a mean had been obtained: the time by the chronometer was again read off at the end of the series.

From this proceeding arose a set of entries of the following order:—

Time.			"Rolling" readings.	Differences, or angular value of "rolls."
h.	m.	s.		
1	21	30	92·0°	2·7°
	,,		94·7	3·4
	,,		91·3	1·9
	,,		93·2	2·2
	,,		91·0	1·0
	,,		92·0	2·0
	,,		90·0	2·1
	,,		92·1	3·4
	,,		88·7	3·1
	,,		91·8	3·4
	,,		88·4	2·3
	,,		90·7	2.2
	,,		88·5	0·5
	,,		89·0	2·3
	,,		86·7	2·4
	,,		89·1	3·6
	,,		85·5	2·3
	,,		87·8	3·2
	,,		84·6	3·4
	,,		88·0	4·3
	,,		83·7	4.1
1	23	10	87·8	

Interval of time = 1 min. 40 secs. Processional effect = 7°, not taken into account.

No. of rolls = 21. Sum of degrees = 55·8°.

Mean angular value of a roll = 2·7°. Mean period of a roll = 5 seconds.

The above is a real case, which I took on board the late steamer *Edinburgh*, in the Baltic, on the 27th of July, 1859; and the two final conclusions, *viz.*, the mean angular value of a roll and the mean period of a roll, were the forms into which I found it most useful in general to compress the results of observation; that is, to give from the mean of twenty or more observations the average period, in seconds of time and the amount in degrees, of either a "roll," or a "pitch," or a "yaw," of the ship, as each of them might be observed one after the other, and thereby establish the normal character of the sea or the movements of the ship upon it for that particular time.

On the occasion just mentioned, when the period of a "roll" was found to be five seconds, and its amount 2·7°, the period of a "pitch" was found to be eight seconds, and the amount 0·6°; the motion of the ship being described as "gentle and pleasant" to the feelings. But the movement had been described to be decidedly disagreeable on a previous occasion, when a "roll" had a period of four seconds, with an amount of 5·5°; and a "pitch," a period of three seconds only, with an amount of 2·7°. In fact, that was a case of crossing the North Sea against an easterly ground swell, and with a N.E. wind on the beam; while the pleasant one was going free before a west wind. This mode of registration, even in these simple average particulars, told a great deal.

There is, however, much more in the movements of the ship and sea than average particulars will always bring out; for series of individual observations sometimes brought clearly to light the existence of extensive undulations, or the effects of the interference of different sets of undulations of the waves, and of ship oscillations, of a long period. Thus, on the 24th of July, 1859, in the North Sea, when the average merely gave, for a "roll," 5° in five seconds; and for a pitch, 1·9° in three seconds, the individual observations gave the following results for the values in degrees of successive "rolls" and "pitches."

Rolls.	Pitches.	Rolls.	Pitches.
11·0°	2·0°	2·5°	2·0°
12·0	2·0	2·8	2·0
7·5	3·0	1·2	1·0
3·5	2·0	4·0	2·3
2·0	1·0	8·0	2·5
2·3	0·8	14·0	1·0
1·8	1·5	11·0	0·8
1·0	1·9	11·4	1·0
1·5	3·4		1·0
0·3	3·7		1·0
0·2	3·5		

The above numbers, together with the following small table of mean results, will probably indicate alike the sensibility of the rotatory ship-clinometer, and the very complicated nature of the phenomena which it is required to observe.

Date.	Rolls.		Pitches.		Yaws.		Locality.	Circumstances.
	Angular extent.	Period.	Angular extent.	Period.	Angular extent.	Period.		
1859.	°	secs.	°	secs.	°	secs.		
July 23rd— 3 P.M.	1·0	8·0	1·5	2·0	0·2	3·0	Frith of Forth.	Course, E.; wind, 5 N.E.
„ 4 „	...	...	1·3	2·5	...	...	Entering North Sea.	
„ 9 „	2·0	4·7	2·0	2·0	...	...	North Sea.	Course, E.; wind, 7 N.E. All sails set; pitchings sensibly greater than rollings.
July 24th— 9 A.M.	5·5	4·0	2·7	3·0	...	...	North Sea.	Course, E.; wind, 8 N.E. Ground swell and wind waves.
„ 10 „	5·0	5·0	1·9	3·0	...	...		
July 25th— 9 A.M.	4·6	5·5	1·4	6·0	...	...	North Sea.	Course, E.; wind, 5 W.N.W. Motion easier.
„ 10 „	5·4	5·4	...	...	1·3	5·0		
July 27th— 1 P.M.	4·3	5·0	...	...	...	...	Baltic.	Course, E.N.E.; wind, 12 W.S.W. Motion feels gentle and pleasant.
„ 1.21 „	2·7	5·0	0·6	8·0	...	...		
July 28th— 8 A.M.	4·3	4·2	1·7	5·5	...	...	Gulf of Finland.	Course, E. by N.; wind, 14 W.
„ 9 „	5·2	5·0	...	...	...	...		

The foregoing observations were all taken on board the late iron screw-steamer *Edinburgh*, of 780 tons register, but carrying about 1,000 tons, chiefly of iron castings with a few bales of cotton.

ON THE CONSTRUCTION AND SUPPORT OF IRON AND OTHER MASTS AND SPARS.*

By Charles Lamport, Esq., Assoc. I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 28th, 1863; H. Chatfield, Esq., Vice-President, in the Chair.]

The strength and fitness of the masts and spars of a ship, for the services they have to perform, are elements in the success of the whole sailing machine, as important as the strength and durability of the hull itself. Broadly considered, however, there has been during the last twenty years no important change effected in the masting and sparring of vessels, excepting such as has arisen from the necessity to supplement the natural deficiencies of the original material—wood, or from the substitution of an entirely different material—iron. The absence of improvement may indicate either the conventional apathy, so common in nautical affairs with regard to appliances for wind propulsion, or it may mark the attainment of a certain amount of perfection, which may be varied, but not extended; or, so little may have been left to be hoped for by alteration as to make it unwise to provoke the risk which changes must entail.

However this may be accounted for, the introduction of iron and steel in place of wood, for the masts and spars of ships, fairly re-opens the whole question. The stereotyped conventional arrangements which it might be rash to disturb in one material, are forced upon the consideration of naval architects when it becomes necessary to substitute another.

The comparison of the resistance to various strains of wooden and iron masts, and of the structural economy and durability of the two, are questions for mechanicians. Practical seamanship is at fault, and the question, freed from the limits of mere experience, is brought back to the test of first principles. This consideration of the matter must be my excuse for now introducing the question.

In designing an iron mast, the first and most obvious consideration is to determine the nature and degree of the strain it has to bear; the second, to arrange the material in quantity and shape most effectually to meet that strain; and the third, to modify the

* Received March 24th, 1863.

relation of the two, so far as the requirements of their application will allow, in order to suit the capabilities of the new material.

1st. As to the strain. The pressure of the wind, being parallel to the surface of the water, and the line of the shrouds being nearly at right angles to that surface, and the resultant force being between the two, the normal strain the mast has to bear, is brought upon it as *upon a column*. The eye of the mechanic at once sees that the mast is a "shore" or derrick; and the experience of every nautical man proclaims that, unsupported by the shrouds, no mast can uphold its own weight during the violent motions of a ship at sea. Its own weight, multiplied into the square of the velocity acquired when rolling or pitching, will produce a momentum beyond the capability of any mast to sustain *as a beam*. Hence, to design an iron mast with a view to resist the maximum transverse strain that may be brought upon it would be a waste of material. On the other hand, to answer to the demands upon its strength, *as a column*, consistently with the exigencies of its form and weight, will be to effect the highest results with the least expenditure of means.

As regards the requirements of its form and application, the objects to be aimed at are, lightness, absence of bulk, ease of maintenance and repair, and a provision for cutting away. To embody these as fully as possible, and to secure the qualities of a pillar, as opposed to a beam, we must give up the poetical idea of "taper spars" and of the tall masts, bending "like a fishing rod," and draw our illustration more usefully, and in a more dignified manner, from the human spine, the vertebrate articulations of which, upheld by muscular supports, combine at once columnar strength with easy undulating motion.

In a hollow pillar, the metal of which is arranged in a thin ring on the circumference, every particle should be brought as nearly as possible into the direct line of the strain applied. To *taper* a mast, therefore, would be to bring the pressure applied, or counteracted by the shrouds, *within* the line of the circle of any given portion of length, below any given point; and the tendency, whenever the strain was thrown upon the circumference unequally, as it must be at sea, would be to cause the mast to "buckle," and to fail. A distinction should be made between the tapering or curved perpendicular outside line of a *solid*, or even of a hollow *cast-iron* column, when such curving is made by increasing the thickness of metal in the middle of its length as a precaution against flexure, and the tapering or other irregularity of longitudinal form when the pillar is made of thin plates of equal thickness throughout.

The effect of "wedging" a mast at the partners is necessarily to convert it into a beam in the position least capable of resisting any transverse strain; namely, fixed at one end, and loaded at the other.

I consider that for iron masts the usual plan of "wedging" should be abandoned, provision being made, however, to give support to the mast at the exceptional periods of masting or of stripping the rigging. With the taper form, and with the plan of wedging, I would further abandon the idea of *flexibility*. The lower mast, topmast, and topgallantmast, should all be rigid in themselves, but yielding with an articulated flexure to the elastic spring of the shrouds and stays. For a pillar *to bend*, is the first step towards *breaking*. Rigidity is its most essential condition, and to combine this quality with the power of yielding to the play of the rigging, each mast should oscillate from the heel. To effect this, I would apply a cast-iron foot, terminating in a ball a little flattened in the fore and aft direction to prevent the mast turning, and widening above, to give a flat, even, but moveable support to the plates of the hollow mast. The flattened ball works in a cast-iron socket or step. Mr. Eaton Hodgkinson, in his work on the "Strength of Materials," adopts a much higher constant in the formula for determining the strength of hollow columns when the ends are *flat* and fixed, than when they are rounded, the figures for the former being 77·2, and for the latter, only 22·7.

To advocate a ball-ended mast as being stronger than one with a flat fixed end, therefore appears at first sight to be wrong; but paradoxical as it may seem, the cast-iron termination really secures the end aimed at by Mr. Hodgkinson, *viz.*, to keep the strain in a line with the metal. When the direction of the pressure is constant and the column is immoveable, a flat fixed bottom conduces to its highest strength, but when the line of the strain varies, as in a swaying mast, and the mast oscillates freely from the bottom, the support of the flat end should move along with it; and thus, a solid flat-topped cast-iron foot, with a round termination below, supplies to the mast the advantageous condition of being technically and really flat ended.

The formula established by Mr. Hodgkinson, by numerous experiments, in correction of Euler's theorem, for determining the strength of hollow columns, is as follows: $w = e \frac{d^{3\cdot6} - d'^{3\cdot6}}{l^{1\cdot7}}$, where e is the constant for flat-ended pillars of more than thirty times their diameter, d the outside diameter, d' the inside diameter, and l the length.

The formula established by Dr. Fairbairn, in his elaborate and valuable experiments to determine the best form and arrangement of material for the Britannia Bridge, is for hollow circular wrought-iron tubes, as follows: $w = e \frac{a \times d}{l}$, where e is a constant ($14\frac{1}{2}$ tons), a the area of metal, d the diameter, and l the length in inches.

These formulæ give respectively for the columnar and transverse strains, in a mast from heel to hounds of 60 feet, of 27 inches diameter, and made with $\frac{1}{4}$-inch plates rivetted to three T irons 4 inches by 4 inches, as follows:—

For the columnar strain - - - - - - -	505 tons.
For the transverse ditto, when supported at both ends and loaded in the middle from partners to hounds, 48 feet - - - - -	21·48 „
When fixed at one end and loaded at the other, as in a mast - - -	5·37 „

The error of crippling a mast by wedging at the partners, so as to convert it into a beam under the last stated condition is thus made glaringly apparent.

The formula adopted by Mr. Hodgkinson for red pine pillars is as follows:— $w = e \frac{d'^{3\cdot6}}{l^{1\cdot7}}$, where e is a constant (3·47), d the diameter in inches, and l the length in feet. The strength of a red pine mast of 27 inches (Mr. Hodgkinson gives no constants for pitch pine, or yellow pine), 60 feet from heel to hounds, as a pillar, is therefore 468 as compared with the 27-inch iron mast, showing a strength of 505 tons. The difference as thus shewn is equally marked in smaller masts. In the case of an iron mast suitable for a ship of from 500 to 600 tons, the mast being 18 inches diameter, and 50 feet from heel to hounds, and made with $\frac{1}{4}$-inch plates, the results are:—

As a column without ⊤ or angle iron - - - - -	160 tons.
As a beam, loaded in the middle - - - - -	7·61 „
As a mast wedged - - - - - - - -	1·90 „
An inch greater diameter, say 19 inches - - - -	187· „
A wooden red pine mast, as a column, 20 inches diameter and 50 feet long	216· „

These results appear to establish the superior strength of iron masts, even of $\frac{1}{4}$-inch plates when uncrippled by wedging, as compared with wooden ones of ordinary dimensions. To deal with a mast whose duty is to withstand a normal strain as a pillar, only simplifies the calculations as to weight of material, and minutiæ of construction. Rigidity is the element most necessary to be maintained in its integrity. To bend under perpendicular pressure is weakness—for the plates to "buckle" is destruction. On the other hand, perfect rigidity and free oscillation will raise the measure (theoretically) of a mast's endurance till it equals the *crushing* resistance of the metal itself.

I will briefly enumerate the particulars of construction of an iron mast calculated, in my opinion, to uphold its strength and endurance under all but the most exceptional conditions. The plates should be of the very best iron, of $\frac{1}{4}$-inch thickness for masts for vessels not exceeding 1,200 tons, as I have already shewn, that thickness ensures an excess of strength over wooden ones of ordinary dimensions. The masts of the *Aerolite* of 1,160 tons, and now of nine years' standing, are still perfect and satisfactory. A greater thickness would add unnecessary weight, unless adopted by dispensing with internal ribs, and so reducing the rigidity; and thinner plates would not allow substance sufficient to resist accidental blows or local pressure. The plates should be in breadth one third the circumference of the mast, and as long as practicable. Plates of half the diameter, in

small masts are often eraeked, or injured by bending to the half eirele. These plates break the butts on the round, and the jointing detraets less from the strength of the strueture either for a eolumnar or transverse strain. The butts should be earefully planed, so as to fit fairly and elosely one on the other, otherwise the pressure is sustained not by the plate, but by the rivet. The rivet holes should be bored, not punched, and the process of rivetting eontinued until the rivet is so mueh cooled as to shrink as little as possible in the hole. The sides of the plates should be rivetted to the sides of three T irons, running from the head to the heel of the mast, with strong cross stays at frequent intervals, but suffieiently apart to allow a boy to mount by them to elean and paint the inside.

The head or doubling should be so arranged as to ensure the pressure from the heel of the topmast, &c., to be as near the centre of the mast as practicable, and at the same time to allow the drag of the shrouds to be fairly over the plates of eaeh side. These desiderata are easily attained by earrying up the plate on the aft side of the mast in a straight line to form the back of the doubling, rivetting a strong plate over the round of the mast at the hounds to a strong angle iron running round the outside, and building upon it the remaining three sides of the square "doubling."

The mast head is, therefore, on three sides a square, formed upon the after side of the round termination of the lower mast at the hounds, the aft side being eurved by carrying up the plate of the round portion.

The topmast heel is housed on the flat plate at the hounds, and the clumsy eheeks whieh may be neeessary for wooden masts are wholly dispensed with. The eap is left large enough to leave the topmast ample play on all sides, the aim being, as in the lower mast, to allow a free oscillation from the heel, and to restriet its normal strain to that of a pillar.

The mast head or doubling, and the cap, therefore, have little else to do beyond sustaining the mast when unsupported by the topmast shrouds and baekstays. The mast head should be fitted with a eover overlapping, but not elose to the sides, so as to keep out wet, while allowing free egress to the air and gases from the hold, whieh are admitted to the interior by numerous small holes left in the plates from the heel to elose under the deek. The mast should be strengthened at the partners by a double plate to sustain the pressure due to the mast's own weight when unsupported by the rigging.

Iron masts may be made into safe and effieient lightning eonductors, by bringing the metal into connection with a keelson bolt, clinched on the under side of the false heel. By this simple preeaution the eleetrie fluid may be freely discharged, and the ship's safety insured. Lastly, provision should be made to eut away at least the main mast in case of need. The safety of the ship may require the loss of the mast, and no less so,

that it should be effectually got rid of; otherwise the deck may be torn up when the shrouds are cut.

To the mast of the *Aërolite* I applied a cutting-away arrangement as follows:—The masts were in two lengths. The lower piece reached about 2 feet above the deck, and had strong angle iron riveted round, in the horizontal rim of which, oblong T shaped slots were cut, every 3 inches of the circumference. The upper length had a similar angle iron affixed, holding T ended bolts corresponding to, and fitting into, the slots. Below the angle iron of the lower portion of the mast was a loose flat ring, with T shaped slots, through which the bolts also passed. When, therefore, the ring was moved, each bolt was simultaneously locked. The ring was at once held firmly in its place, and turned when required by a horizontal worm working into three or four teeth cut into the rim. A few turns locked or unlocked the T ended bolts at will, and kept the mast firm, or severed it, as required. The ring should be of brass, to prevent the bolts and screw rusting from disuse. A plan more simple and less likely to get out of order, would be to have broad angle irons with long pins fast to the upper, and going through holes in the lower, and serving as belaying pins. A simple lashing, or a few lockings driven through the lower ends, would be necessary to sustain the mast when unsupported.

Iron and Steel Topmasts.

The lightness and cheapness of large sized iron masts, as compared with wooden ones of equal dimensions, are advantages which appear to me to be wanting in iron, and, as far as cheapness is concerned, in steel topmasts, for merchant ships of average size. The first cost of iron lower masts is greater in the case of vessels less than 600 to 700 tons; and it is only for vessels of 1,000 tons and upwards that the gain is a decided one. In the case of topmasts, the balance is, except in strength, altogether in favour of wood. Ordinary sized topmasts are readily obtained, and the weight of one of pitch pine of 12 inches diameter is about the same as that of iron of $\frac{1}{4}$-inch plates, without angle iron or other interior ribs. One of steel, if of $\frac{1}{8}$-inch plates, would be rather more than half the weight, steel being as 1·02 to 1 of iron.

The relative strengths of iron, steel, and wooden topmasts, by Mr. Hodgkinson's formula, are as follows:—

AS A PILLAR.		AS A BEAM.	
Wrought iron $\frac{1}{4}$-in. plates, 12 in. diameter, 30 feet hounds	133 tons.	Wrought iron $\frac{1}{4}$-in. plates, 12 in. diameter, 20 feet from cap	6·8 tons.
Ditto ditto $\frac{3}{16}$ plates	101 ,,	Ditto ditto $\frac{3}{16}$	5·0 ,,
Steel ditto $\frac{1}{8}$,,	90 ,,	Steel ditto	5·9 ,,
Red pine	82 ,,	Red pine	2·8 ,,

The steel constant 111·1, as compared with 77·2 for iron, is for *cast* steel, and is, no doubt, higher than for homogenous metal or puddled steel.

I am no advocate for the use of plates, even of steel, so thin as $\frac{1}{8}$-inch. Internal oxidation may reduce the thickness very rapidly, and there is very little substance for counter-sinking the rivet holes. In instances where very thin plates however are used, I should avoid flush rivetting, and employ three or more upright ribs of iron, applied outside, to take the chafe, and allow the ready movement of the parell to maintain the integrity of the columnar strain; I would lead the topsail tye through an eye bolt or swivel block on the after side of the parell. In this case, by carrying the halliards well aft, and to the windward side of the ship, a preventer backstay would be obtained, *always applied in direct contravention to the forward pressure of the topsail yard, at whatever position on the topmast it may at any time be placed.*

Construction of Yards.

The normal strain upon any yard is a transverse one, and the component metal should be arranged to meet that strain so as to secure the proportion of 6 to 5, for compression as against tension. Probably the most economical mode of doing this would be to make the jackstay of angle iron well riveted to the yard, and with holes punched in the projecting rib, for attaching the sail. In the topsail yard, if adapted for Cunningham's reefing, the angle irons attached outside might help to keep the parallelism of the yard, while they materially increase its strength.

As compared with a pitch pine yard, I calculate the relative strengths of iron and steel as follows:—

Pitch pine - - - - - - - -	$4\frac{1}{2}$ tons.
Iron $\frac{1}{4}$ inch. plates in the middle, no angle iron - - - -	5 ,,
Steel ditto - - - - - - - -	7·7 ,,

Probably the maximum wind pressure a yard of the above strength would ever have to bear, may be measured by a force of 25 lbs. to the square foot on a close-reefed topsail spreading 800 or 900 square feet, or in round numbers, a total force of 10 tons, of which some 6 would belong to the lower yard, if unsupported by braces. Of course the braces if properly watched must materially, if not altogether, take off this strain; but on the other hand, a less force, if applied as it might be, by a jerk, would severely tax the strength of the yard. As it must be impossible at all times to guard against such trials, perhaps the wisest course would be not to provide a strength equal to every emergency, but to adopt some modification by which the injury, if inflicted, can readily be remedied.

To this end I would suggest that the lower yards should be constructed in the following manner:—One third of the cleated length for the centre portion should be formed as a wrought iron or steel tube, slightly bell-shaped at each end, and with a strong plate in the middle at right angles to the length. Into each end I would insert wooden arms, and fix them by a single loosely fitting bolt as near the middle of the tube as practicable, the object being to allow each arm to move freely in the tube sockets *to a certain extent, but no further.* To counteract the upward lift of the topsail, the topsail sheets should be brought together about 3 feet below the middle of the yard by the ordinary block from the mast, so as to form guys or stays. As each arm would move about 2 feet out of a straight line, any inequality in the support of the braces would be at once detected, and the support to the yard always maintained by them, while the tube would carry the ends round when staying, &c.

The advantages would be flexibility *without strain*, and for renewal, instead of a cumbrous expensive spar of full length, just half the length, or two halves at much less cost, would only be requisite; and if broken at sea, the refitting would be easily effected. A little sheet of india-rubber or leather might be beneficially employed where the end of the tube presses (in staying) on the wood. I need hardly say that any combination of wood and iron in the shape of a cross, merely adds weight without strength, as disposing the bulk of the metal in the neutral axis, where it is worse than useless.

The Support of Masts, &c.

The efficient support of the masts of a ship is a question of equal importance with that of the mast's capability to maintain its portion of the duty of propulsion. In fact, considering the masts as pillars, the measure of their support is the measure of their efficiency. The difficulty in a ship is to apply that support so as to obtain the most ample results with the least expenditure of material, and the minimum interference with the proper working of the ship. The problem for solution is to apply a given amount of support most usefully, under the conditions of working efficiency. Every step in its solution necessitates a compromise.

The masts have to be supported laterally, as well as fore and aft. It would be easy by "spreading" the rigging to give a more direct support against the *forward* pressure of the wind, but what is gained in this direction is lost in the power to uphold the mast against the *side* pressure. Again, the more complete the support, the more rigid becomes the system of masts and yards to the loss of a certain storage or equalization of force absorbed, and given out by their elastic play.

That spring, and consequent momentum, should depend, as I have shewn, upon the elasticity of the shrouds *entirely*. If we adopt wire rigging we must sacrifice more or less of this advantage. We make a compromise between the lightness and less resistance presented by it to the air, "on a wind," and the play and momentum of the whole system. The question of elasticity is further involved in that of *simultaneous* and *combined* support. By attaching the shrouds to the lower mast *at one point* (at the hounds) and spreading them on the ship's side, each one becomes a radius of varying length, and proceeds from different centres. When the mast plays, the aftermost shroud has an unequal amount of work to do, and it is only *by stretching*, under an increasing strain, that the efficient help of the others is obtained. If the shrouds were perfectly rigid, we should have the enactment of the old fable of the separated bundle of sticks, while the stretching of hempen rope, by fusing the elements of strength, gives out the maximum result. At the moment (in time) of inertia, all the shrouds "*bear*," and the maximum support is given. If the shrouds had no elasticity whatever, and no pressure ever inclined the mast, that maximum support would be maintained under such pressure. If the shrouds be properly elastic, stretching and contracting as occasion required, such property would uphold the maximum support, by diffusion, under the varying conditions of the mast's play; but in the case of a support which stretches without being properly elastic, the shrouds bear the strain *seriatim*, become injured, and the mast suffers. Further, the gathering of the rigging at the hounds is of disadvantage from harbouring wet and promoting decay. It has also the mechanical disadvantage of concentrating the mast's support upon one point. As with a beam, to spread the weight is to diminish its pressure, so to diffuse the support is to increase its strength.

To obtain this diffusion of support, where there is a transverse strain on the mast head, as in the case of a double topsail yard, I adopt the separate attachment of each pair of shrouds, at points varying from the cap at the mast head, to the truss hoop of the lower yard. Further, I propose to combine the advantages of both hemp and wire rigging, by the use of the former for the two aftermost shrouds, and of the latter for those whose sustaining power comes later into play. Or, to effect a more perfect equalization of strain upon the whole, I propose to connect the first and last shroud, passing them over a runner, or using a lever with a screw for setting up, at the rail, and also the second and last but one, and so on. By this expedient the greatest differences severally adjust themselves to the benefit of the whole. One of the advantages of the separate and diffused attachment of the shrouds is to permit the lower yard to be braced more sharply fore and aft without chafing. This advantage entails a second advantage by permitting the topsail sheets to be carried to a block against the mast instead of under the yard, and so obtaining efficient guys or stays for strengthening the yard.

Relative Measure of a Mast's Efficiency.

The calculation of the entire strain upon a mast at sea is a difficult and inconclusive one. The pressure upon the sails may, with given wind forces, be easily estimated; and the momentum of the mass of masts, spars, and rigging, under certain conditions of rolling, pitching, &c., may be approximately ascertained; but the strain from the wind pressure, plus the momentum from violent motions, and varying at every angle of inclination, can only, I think, be vaguely deduced.

Practically, however, we have a test within the compass of which the ever-combining, and the constantly-varying, strains may be held to lie. If we know the breaking strain of the supporting shrouds, and their mechanical application or leverage to the masts, we know that the duty of the latter must be less than this amount.

Take the case of a ship of 500 or 600 tons. The breaking strain upon her shrouds and backstays may be assumed to be 200 tons, and the average angle of their "spread" to be 10 degrees. Then, by the parallelogram of forces, the maximum tension on the shrouds gives a maximum pressure of 198 tons on the lower mast, and a maximum equivalent force from wind and momentum of 33 tons. Hence, it appears that the total pressure that can at any time be brought to bear upon the mast must be less at all times than the breaking strain of the supporting shrouds; and the more the mast inclines forward, the greater the difference becomes, or the relatively less strain it has to bear.

More than 33 tons pressure from wind and momentum would break the shrouds, and yet the actual pressure need not be measured by this limit, inasmuch as the braces and other ropes assist to sustain it. But it is the entire equivalent due to, and affecting the masts and shrouds. If the mast will bear a pressure of 200 tons in a ship of from 500 to 600 tons, and the shrouds are proved to be, in practice, strong enough, we may be satisfied that we have attained sufficient strength.

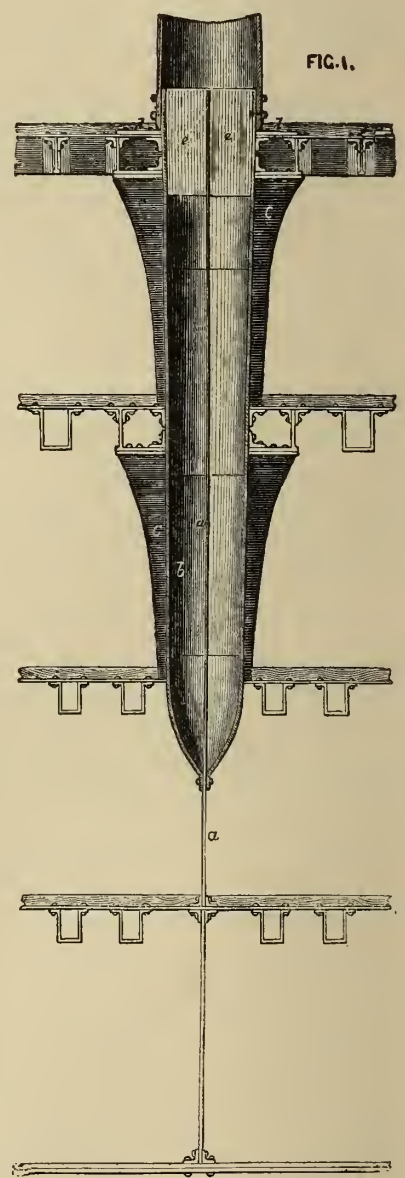
How much less strength would do, I scarcely think we could safely determine. The data at command are meagre, and our results are only comparatively satisfactory. In iron masts the room for differences, due to bad workmanship, and bad material are very wide. If the proof be deemed indispensable for the anchors and chains of ships, why should the masts and spars be passed over without test? The one class of appliances are as indispensable to a ship's safety as the other. A few preliminary experiments instituted under proper superintendence, and a rule that all variations shall be satisfactorily "proved," would very soon supply an amount of information on this subject which would be as interesting, as it might prove beneficial, to every branch of the shipping interest.

DISCUSSION.

The CHAIRMAN (H. Chatfield, Esq., Vice-President, I.N.A.): Gentlemen, we have heard a very interesting Paper on the masting of ships. This is a Paper of the greatest importance, and the gentleman who has delivered it shews that he has paid very great attention to the subject. The subject is one in which I take the greatest possible interest. There may be some points upon which I do not quite agree with Mr. Lamport, but upon the whole it is a very excellent Paper.

Capt. SYMONDS, R.N., Assoc. I.N.A.: It is with some diffidence that I rise to remark on a subject of this description. I will, however, make one or two suggestions which I think may bear on the point. Mr. Lamport insisted (and I believe very properly) upon the rigidity of the whole structure in an iron ship. My experience at sea has gone to shew that if the masts work the ship suffers somewhere, and I think I am right in saying—perhaps some of you will correct me if I am wrong—that the partners and water-ways are generally the parts that suffer most. My idea is that we should have some additional strength in those quarters. I will lay before you a plan which I think is a stronger and better method of stepping and securing iron masts than that now in vogue. The method is not entirely my own, but originated with Mr. Richard Roberts. Instead of stepping the mast on one point, as is now the case, by this arrangement every part of the ship in the vicinity of the mast bears a proportion of the strain. We assume that the whole structure will thus acquire an amount of rigidity which it is impossible for it to have when the mast is stepped in the ordinary manner. Instead of making the mast in one length from head to heel, as it is usually made, the lower or housed part is separate from the upper, and is riveted to the transverse bulkheads. The accompanying engravings shew the connection of the bulkhead with the mast. Fig. 1 is a longitudinal section of the mast, and shews the bulkhead (*a*) with the two halves of the mast (*b*) connected with it. The halves of the mast are again connected with the decks by means of angle irons or knees (*c*), which also support the decks. The lower part of the mast projects sufficiently above the upper deck to admit of the upper portion of the mast being stepped over it. The upper portion rests on a thick flange or plate (*d*), and is secured to the lower portion by a double row of screw bolts. The part which projects is strengthened by the cross piece shewn at (*e*). Fig. 2 shews the elevation, and Fig. 3 the plan drawing at the point of juncture of the upper and lower parts of the mast.

FIG. 1.

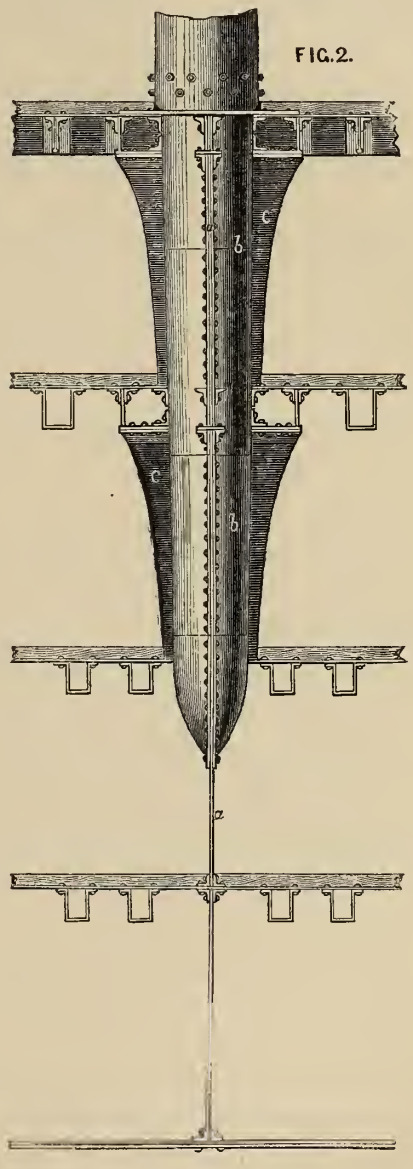


Now, one of the objections which may be brought against this method of stepping the mast is, that you cannot cut it away readily; but, I believe, that if it were deemed expedient to cut the mast away, it could be done easily. I believe that after the removal of the screw bolts,

the mast would go overboard, that is, in such weather as would render it necessary to get rid of the mast. But, on the other hand, I should very much prefer not to get rid of an iron mast, because my experience is, that a ship brings considerably more strain upon her cables and anchors when rolling heavily without masts than she does when with them standing, as they materially lessen her rolling. There is one point in the Paper which I do not quite agree with. I think I understood Mr. Lamport to say that he should recommend a mixture of hemp and wire rope for the shrouds, to ensure elasticity, &c., that the strain might be more equally diffused throughout the whole. I have taken some trouble to make enquiries of those who have used wire rope to a considerable extent, and the position they take is this,—that even when the rigging is set up as taut as possible, there is still sufficient elasticity remaining in the iron to convey (what Mr. Lamport rightly insists on) the diffusion of strain throughout. I think, in practice, that it is found to be so; and my experience is decidedly in that direction.

With respect to his plan for fitting topmasts for iron masts, it is no new idea, but simply the revival of a thing which has been insisted on by many of my profession, as well as by many in the merchant service. Some persons think that a telescope mast might be used with advantage; and with this view I concur. I believe that if we use single masts, which I hope we always shall do in preference to tripods, such dimensions may be given as will prevent their being injured by perforation by shot. We shall, then, have ample space at the mast head for fitting cross-trees internally, so as to allow of wooden topmasts being used telescope-fashion. I think we can give ample support to a mast of such dimensions by rigging, and do away with a great deal of the top hamper, now used in fitting mast heads.

FIG. 2.



Capt. De Horsey, R.N., Assoc. I.N.A.: I shall make but one remark concerning the Paper I have just heard. I think Mr. Lamport told us that he recommended the halliards, or the tie, as we call it, of the topsail-yard being brought down the weather side, for the support of the topmast. I believe that, as practical men, we shall see that it cannot be done. I do not know whether I shall be out of order in saying one word about the engraving which has been exhibited by Capt. Symonds. I did not quite understand it: it appears to me that the mast supports the decks as well as the decks support the mast.

Capt. Symonds: The whole of the weight does not bear on the bottom, but is equally divided between deck, bottom, and sides. All parts of the ship in that vicinity bear their proportion of the weight of the masts and the strain they would otherwise bring on one point.

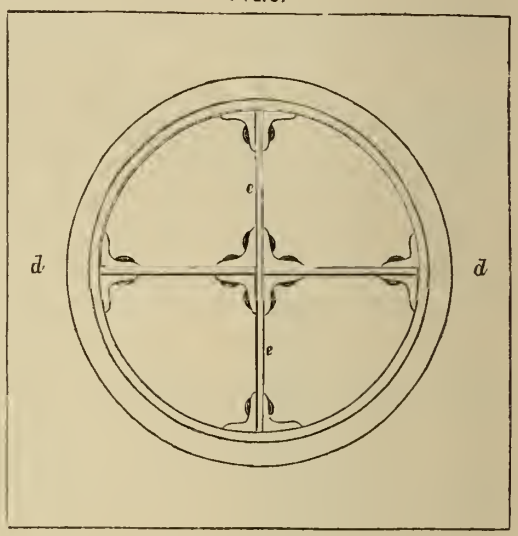
Capt. De Horsey: The weight is divided, if I understand right, on the keelson at the bottom, and also on every deck. Notwithstanding which, the decks are supported by the masts as far as I can see.

Capt. Symonds: Yes. The bulkhead is the main support. The bulkhead contributes materially to support the deck and masts.

Mr. T. J. Ditchburn, M.I.N.A.: Allow me to ask Capt. Symonds whether any provision is made for cutting away his mast, if required?

Capt. Symonds: Yes; I think, that under the circumstances in which it might be advisable to cut the mast away, it would go by the board if the bolts were removed. Being joined about two feet above the deck, if you take the rivets out when the ship is rolling the mast will clear itself without much cutting. But I remarked just now that I considered a ship would ride much easier with her lower masts standing than she would if they were cut away.

FIG. 3.



Mr. Ditchburn: The screw bolts or rivets are very awkward things to remove when you are getting in such a predicament as to require it?

Capt. Symonds: I think not.

Mr. Ditchburn: In the event of the mast going overboard, would it swim?

Capt. Symonds: No; I should prefer it sinking, to clear the ship without fouling or breaking the screw.

Mr. Ditchburn: Then, in the case of a wreck, the wooden mast has the advantage over the iron one. Is it absolutely necessary to have a bulkhead to place it on?

Capt. Symonds: No, I consider the iron mast preferable; and I think it is quite competent for any naval constructor to arrange his bulkheads and masts in such a manner that they should come together. I am, perhaps, taking rather a bold position in respect to this question of fitting iron masts. I wish my friend Mr. Richard Roberts was well enough to be present, for I have no doubt that he would answer your questions far better than I can. I believe that many high authorities on such matters, besides Mr. Lamport, have long since given their opinion in favour of iron masts for iron ships, and, as a seaman, I quite concur with them.

Mr. Ditchburn: It appears to me that the iron mast would not be equal to that which it is intended to supersede.

Mr. Lamport, Assoc. I.N.A.: I must confess I am exceedingly disappointed at the little discussion which has arisen on this question. I confess this, because my object in starting the subject was not to presume to give you any information whatever, but in the hope that we might derive some information from a discussion. I should be tempted almost, if the time were not too far advanced, to discuss my own propositions, because to a certain extent only am I satisfied about them. I did hope that some gentleman would have taken up cudgels on behalf of that novel mode of rigging which Capt. Cowper Coles exhibited here to-day. I must confess it appears to me, that such an arrangement of mast is

perfectly impracticable. It also appears to me that such a mast as that which Capt. Coles advocated would on the first roll of the ship, from its own weight and momentum, go over her side. Of course, the advantages incident to the tripod mast for a vessel in Her Majesty's Navy is a question which I do not enter upon. But as a question of rigging, I do consider it a futile expenditure of useful material, and one which will defeat its own purpose. I repeat, if there be any truth in the formula of mechanicians, that topmasts, made, as I understood Capt. Coles would make them, of something like $\frac{1}{2}$-inch iron, 26 inches in diameter, with the usual number of strong ribs inside, would, on the first roll of the ship, be carried overboard. No structure as a beam could sustain the strain. I want to suggest a point in regard to the plates. The ship *Aërolite*, of 36 feet beam, and built nine years ago, had a mainmast weighing only 4 tons. She has been in two typhoons. She was blown ashore high and dry, but the masts were uninjured. They were formed of $\frac{1}{4}$-inch plates. The other day an eminent shipbuilder ordered masts for a ship of 32 feet beam, and of about 800 tons; and the specified weight was to be between 6 and 7 tons. In the specifications, I saw that the plates of the lower part of the lower mast were to be double the thickness of the upper part. If the mast is to have the strain brought upon the top, as a pillar, which it must have, the thinner plates of the upper part are the measure of the whole strength. If the plates had greater strength in the middle there would be some advantage; but to taper the mast, and to use thick plates elsewhere, is, in my opinion, to waste money. With regard to steel, I would not have it in any ship, and for this reason,—I do not believe any maker will send you plates which you can safely bend into the small diameter required for topmasts and yards; and again, we cannot ensure their being of equal and proper strength throughout. I have known many cases where they have been tried, and have actually broken.

Mr. Peacock, Assoc. I.N.A.: I have much pleasure in corroborating what Mr. Lamport has said with regard to the *Aërolite*. I examined her lower masts some years ago, after she had been in the typhoon alluded to, and I found them perfect. I believe that there is no better system of constructing iron lower masts than that which Mr. Lamport adopts. His plan of spreading the rigging down to the lower yards, I approve of very much indeed. I have great pleasure in saying that I approve very much of his system, not only as regards the rigging, but as regards the way in which he makes the masts.

Mr. E. J. Reed, Mem. Council I.N.A.: As Mr. Lamport has come a long distance to read this Paper, I should like to assure him that it is one of that class of Papers which we are very anxious indeed to get; and the little discussion which it excited, is very much his own fault, for having made it so excellent and unassailable. It is the first Paper we have had on the subject, and I am sure every one who heard it read, must feel it is a subject upon which we can well receive future Papers. I, for one, am much obliged for his remarks, because I am certain that in a particular Service, which I will not mention, there will be a disposition to run into enormous weights for iron masts, unless we look after what we are about. For my own part, I shall have the greatest possible interest in studying Mr. Lamport's Paper; and I hope, so far from considering it any want of success from the slackness of the discussion, that he will consider he has achieved so great a success that he will be induced to come here next year and give us some of his valuable and useful advice.

ON A NEW MODE OF CONSTRUCTING IRON BULKHEADS.*

By George C. Mackrow, Esq., N.A., Assoc. I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 27th, 1863; H. Chatfield, Esq., Vice-President, I.N.A., in the Chair.]

The safety of iron vessels, and the precious freights or living cargoes they carry, being often made to depend upon the efficiency of the watertight compartments, it will not be out of place, perhaps, if I bring before your notice a proposition for constructing the vertical bulkheads, and thus aid in some small measure by the contribution of my mite, to the common fund of practical knowledge in iron ship construction which is sought to be raised by this valuable Institution.

Much has been already written and recorded in the *Transactions* of this Institution by Messrs. Fairbairn, Grantham, Scott Russell, Martin and Ritchie, upon the best modes of constructing iron ships—the introduction of extra keelsons, stringers, and box waterways having been rightly urged.

At our last session Mr. Scott Russell kindly contributed a Paper upon the longitudinal system of framing. The subject was freely discussed, and the general opinion, I think, inclined to a medium mode of construction, *viz.*, a combination of longitudinal with transverse frames as is now generally adopted in our iron vessels of war.

Now, whether the longitudinal system, or the transverse, or a combination of both prevail, it is evident that an efficient system of watertight compartments must always obtain; therefore I think it behoves the naval constructor to determine the best mode of framing, or constructing the vertical bulkheads.

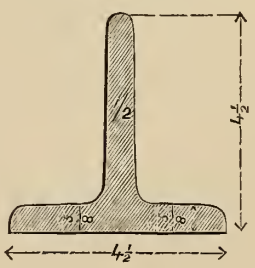
But not to trespass too much upon your time I will proceed to describe briefly the Engravings in Plates VII and VIII, which shew on the one hand, the general mode of constructing iron bulkheads, and on the other hand, what I have thought to be some, perhaps I may be allowed to say, considerable improvement upon the ordinary method.

* Received March 17th, 1863.

Plate VII., represents a bulkhead of the *Paramatta*, a vessel of 3,000 tons, built by the Thames Iron Works and Shipbuilding Company for the Royal West India Mail Company. This vessel was constructed in the usual manner, with the exception of an additional thickness of iron at the middle; the plates there being $\frac{5}{8}$ of an inch thick, while at the sides they were $\frac{9}{16}$ of an inch. The bulkhead was strengthened by bars of angle iron 4 inches × 3 inches × $\frac{3}{8}$-inch, placed vertically on the one side, and horizontally on the other, and they were 30 inches apart. It was during the building of the above-mentioned vessel that I had some conversation with one of the company's officers, and he related the condition in which he found the engine-room bulkhead of the *Tyne*—a vessel also belonging to the Royal Mail Company, and which was wrecked in the Channel some few years back. He said that several of the plates, for the whole of their lengths, had their rivet-heads sheared completely off, and the plates, as a consequence, were overlapping each other some distance. This resulted from the fact of her having settled directly under the engine room bulkhead, which, not being sufficiently strong to support the superincumbent weight, gave way in the manner described.

Now, I am not about to propose a method with a view to aid in the construction of a vessel that shall stand any amount of thumping upon the rocks, and then come off unscathed. Such a vessel, I presume, few practical men expect to see built; but, assuming that there is a certain amount of iron placed at the disposal of the constructor, it certainly behoves him to economize it, or to dispose of it to the best possible advantage. And as it is the last pound that breaks the camel's back, it may not be extravagant to say, perhaps, that if the *Tyne's* bulkheads had been constructed in the manner which I propose, they might not have given way, and the vessel might possibly have been saved from considerable damage.

I will now draw your attention to Plate VIII., which shews the method that I propose to adopt, and a few words will suffice to explain it.



The whole of the bulkhead is worked, what is technically called, "flush" or "jump-jointed," and is supported at the vertical and horizontal joints by T irons, as shewn in the accompanying engraving. These T irons are placed vertically on the one side and horizontally on the other, and form at the same time both butt and joint strips and stiffeners, an angle iron being placed between every alternate vertical T iron as a stiffener. The increased strength is obtained by the whole of the plates being kept in the same vertical line, directly over each other, thereby rendering the shearing off of the rivet heads, as occurred in the bulkhead of the *Tyne*, impossible.

It is to be observed that liners in this method are not required, and thus an economy in iron is obtained, the laps and angle stiffeners used in the old method being in excess of the T irons introduced in this proposal.

The value of such a bulkhead in vessels of war with ram bows is indisputable, where the force or impact of the blow is received first by the stem, and is then transmitted to the middle line bulkhead.

This has been seen by our Admiralty, and they are now carrying it into practice, a bulkhead very similar to what I propose being constructed in the *Minotaur*, *Northumberland*, and *Agincourt*. The objection, however, which I think there is to the plan adopted in the *Minotaur* and sister vessels, is the increased weight of iron over either of the plans before you, the bulkhead being worked flush with vertical and horizontal butt straps, as is usual in flush-work; and the introduction of liners the same thickness as the butt strap, being rendered necessary to receive the angle iron stiffeners.

A comparison of the weights of the two bulkheads, as illustrated in Plates VII. and VIII., will suffice to shew the economy effected. While it certainly is not much, yet if it should be thought that I have succeeded in constructing a better bulkhead, the object which I had in view in writing this Paper will be attained.

We have, then, according to the old method, shewn in Plate VII., the following:—

					lbs.		cwt.	qrs.	lbs.
Area of Bulkhead	in square feet	1,108,	at	23·75	...	234	3	13
Perpendicular Angle Irons ...	(4 × 3 × $\frac{3}{8}$)	430	feet	„	8·3	...	31	3	17
Horizontal ditto ...	(4 × 3 × $\frac{3}{8}$)	375	„	„	8·3	...	27	3	4
Beam ditto	(4 × 3 × $\frac{3}{8}$)	$87\frac{1}{2}$	„	„	8·3	...	6	1	27
Horizontal Lap	($2\frac{1}{4}$ × $\frac{19}{32}$)	368	„	„	4·45	...	14	2	13
Horizontal Liners	(3 × $\frac{19}{32}$)	68	„	„	2·97	...	1	3	5
Perpendicular Laps	($2\frac{1}{4}$ × $\frac{19}{32}$)	107	„	„	4·45	...	4	1	0
Perpendicular Liners	(3 × $\frac{19}{32}$)	210	„	„	5·94	...	11	0	15
Rivet-heads, No. 3,230					·32	each	9	0	25
Total							342	0	7

According to the new method, shewn in Plate VIII, we have the following:—

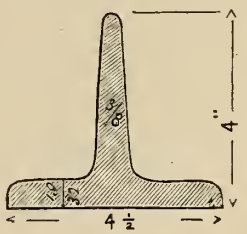
			lbs.		cwt.	qrs.	lbs.
Area of Bulkhead	...	in square feet 1,108, at	23·75	...	234	3	13
Perpendicular Angle Irons ...	...	(4 × 3 × $\frac{3}{8}$) 204 feet	„ 8·3	...	15	0	13
Perpendicular T Irons* ...		($4\frac{1}{2}$ × 4 × $\frac{5}{8}$) 204 „	„ 12·64	...	23	0	2
Horizontal T Irons ...	...	($4\frac{1}{2}$ × 4 × $\frac{5}{8}$) 375 „	„ 12·64	...	42	1	8
Beam Angle Iron		(4 × 3 × $\frac{3}{8}$) $87\frac{1}{2}$ „	„ 8·3	...	6	1	27
Rivet-heads, No. 4,242 ...	...	... ...	... ·32 each		12	0	13
	Total	... ...	...		333	3	20

	cwt.	qrs.	lbs.	
Ordinary Method	342	0	7	
Proposed „	333	3	20	
Difference ...	8	0	15	or about $2\frac{3}{8}$ per cent.

It may be said that this comparison is with a bulkhead of a large vessel, and that it is not usual to put horizontal stiffeners, but I beg to call your attention to the size of the angle irons which are only 4 × 3 × $\frac{3}{8}$ = 8·3 lbs. per foot, whereas Lloyd's Rules gives an angle-iron for a 3,000 ton vessel $4\frac{1}{2}$ × $3\frac{1}{2}$ × $\frac{5}{8}$ = 15·3 lbs., nearly double the weight. Therefore, if I substitute 430 feet of this angle iron at 15·3 lbs. per foot for the 805 feet of angle iron at 8·3 lbs. per foot, we have 58 cwt. 2 qrs. 27 lbs. against 59 cwt. 2 qrs. 21 lbs., giving about 1 cwt. in favour of the old method, and reducing my saving to about $2\frac{1}{8}$ per cent.

But there is another way in which I think the bulkheads might be worked to some considerable advantage with regard to weight, and I should be glad to hear what practical objection there is to it.

I would propose to work the plates vertically instead of horizontally, placing a T iron, which is shewn in the accompanying engraving, at every joint. Plates for vessels of 1,000 tons and under, might be worked in one length, and for above 1,000 tons, in two lengths, having a butt strap at the joint.



* For size of T Iron, see engraving on page 139.

The bulkhead would then stand thus:—

				cwt.	qrs.	lbs.
Area	1,108	square feet, at	23·75 ...	234	3	13
Perpendicular T Irons	408	feet linear	,, 15·36 ...	55	3	23
Beam Iron	87¼	feet	,, 8·3 ...	6	1	27
Rivet-heads, No. 3,230			... ·32 ...	9	0	25
Total				306	2	4

	cwt.	qrs.	lbs.	
Ordinary Method	342	0	7	
Proposed ,, No. 2	306	2	4	
Difference ...	35	2	3	or 10½ per cent.

This last method hardly accords with our notions, and would be entirely rejected for the outside plating; but I should like to put it as a practical question to practical men, whether its adoption in the bulkheads is at all objectionable. It is quite clear that any tensile strain to which the bulkheads may be subjected would come upon the rivets. But will it not be thought that they are fully capable of resisting such a strain? And if they are, a saving of 10½ per cent. is worth consideration, especially in the building of iron-clads, where the iron expended in bulkheads forms a pretty considerable item. I have endeavoured to shew also that the bulkheads are rendered much more efficient.

I may be allowed to observe in conclusion that this is entirely a practical question, and, to any but practical men, will appear matter of dry detail; but I am persuaded, and believe you will all agree with me in this, that any well-authenticated facts or real practical questions in connection with shipbuilding that can be brought before this Institution, must prove of more real value than the most eloquent discourse upon some unknown and far-fetched theory. What we want are facts that can be grasped and dealt with—data upon which we can build, and the gathering together of such is, I believe, the main object of this Institution. Knowing this, I have felt encouraged and emboldened to trespass thus far upon your kind attention.

DISCUSSION.

Mr. Lamport, Assoc. I.N.A: Mr. Mackrow has given to us a remarkable evidence of the inutility of bulkheads in strengthening ships. I have a very strong opinion that the introduction of inflexible points in a long flexible structure, like that of ordinary mercantile vessels, is a very disadvantageous arrangement. A vessel that came under my notice some time ago went out with a full cargo; she met with a storm in the Bay of Biscay, and had to come back to Liverpool leaky. She was put into the dock

there, and it was found that at the foremast bulkhead every rivet was broken, and it was a perfect mystery that in the vibration of the vessel the rivets had not worked out, and the ship been lost. Mr. Mackrow has told us that in the case of an aft bulkhead, strongly constructed, there has been so great a working as actually to shear off the rivet heads, rendering it necessary for him to devise another and improved arrangement, for making that point of the vessel stiffer even than before; or in other words, for rendering that bulkhead a greater disadvantage to the strength of the ship. Assuming the improvement which he advocates in constructing a rigid bulkhead, as such, I take the wider range of the question, as to the application of the bulkheads in the perfectly rigid and strong form which he proposes, to the fabric of a ship. I suggest whether it would not be better, on the other hand, to arrange these bulkheads in such a form, and at such an angle to the side, as will admit of elastic play, so that while you strengthen the hull to a certain extent, it is not injured by absolute inflexibility at fixed points. Although I may be straining this discussion, will you allow me, as I shall have no other opportunity, to say a word or two as regards the use of wood for the construction of ships in future. I have not heard one single word uttered in favour of wood. It appears as if everybody in this room was so far persuaded of the ultimate utility of iron for the merchant service, and Her Majesty's navy, or that the wooden shipbuilders were so thoroughly cowed, that not one word could be said for wood. Now, sir, I must offer just one word of protest against the verdict, in the trial of wood *versus* iron, going by default. Mr. Fairbairn tells us that you cannot make a structure of wood, and one of iron, of the same size, of equal strength. But I question whether you may not build a vessel—which is very different from the kind of structure which Mr. Fairbairn has been so instrumental in perfecting, *viz.*, tubular bridges—equally strong, for a ship is supported throughout the whole of her length. Take the question as to the strength of each material. It is a curious fact, but I meet few persons who admit that wood as a material, weight for weight, is stronger than iron, and yet even with common pine such is the fact. If I take teak I find that, whereas the specific gravity of the one is ten times greater than that of the other, the cohesive force is only about one-fourth, and the transverse strength is only something like one-third less. Weight for weight, therefore, teak is two and a half times stronger, in its tensile capacity, than iron, and as regards its transverse strength, weight for weight, it is three times as strong.

As regards iron ships, another very important question has been raised. It has always been admitted that an iron ship, for a certain amount of displacement for builder's tonnage, possesses a larger internal cubical capacity than a wooden ship. But Mr. Fairbairn tells us, that if we are to make iron ships strong enough, we must do away with that advantage, and by introducing the cellular system, as he proposes, the two materials will be put very much upon the same footing on this point. As to the question of durability, I dismiss the comparison altogether as respects the frames of ships. I believe the liability to dry rot in the frames of wooden ships puts the comparison altogether on one side. Very likely the comparison as regards the sailing of the vessels, from the fouling of iron ships, must also be put on one side, but it does appear to me that by the use of wood over iron frames, we may see our way to the attainment of a large balance of advantages. All I ask you to consider is this—that it should not be taken for granted, that the use of wood is entirely superseded. I do firmly believe that by a combination of the two materials—by the use of iron frames and iron braces, combined with wooden planking—you may obtain a ship stronger, and nearly of the same buoyancy as one of iron entirely—you may obtain a ship of greater durability, and one which can remain at sea for almost any length of time without fouling. As respects the advantage of a ship of war being able to keep at sea without fouling, let me recall to your mind the graphic description

we had yesterday from Mr. Scott Russell, when he introduced to our notice the probable effect of employing small swift ships like the *Alabama* in the future wars of this country, either to protect our own commerce, or to molest that of an enemy. Then let us follow him to the very antithesis, the *ultima thule* of the anticipation, if I may so call it, where he was led to say, that the use of 12-inch armour plates, brought about by the adoption of large rifled guns, would necessitate our employing ships of the size of the *Great Eastern*. I do think, sir, that this is the case again of body armour *versus* bullets, and we may fairly hark back in the search for the ship of the future, and consider whether the two materials—wood and iron—cannot be so utilised as to produce on the speed of an *Alabama*, a better result than the unwieldy invulnerability of ships like the *Great Eastern*. If you put on the *Warrior* and other vessels immense iron plates, do you strengthen these vessels except to resist shot? Are you not adding weight to weight, and piling material upon material, of no use in resisting the straining at sea? And this brings me to another important consideration in respect to the strength of iron vessels. I find in a most valuable work by Mr. Kirkaldy, of Glasgow, who was employed by the Messrs. Napier, and who has made the most elaborate experiments with regard to the strength of iron and steel, the statement of a most important fact deducted from Lloyd's experiments. I am, not, however, prepared to adopt it. It startled me. This statement is, that you cannot obtain from rivetted iron plates a greater strength than that given by material $\frac{3}{8}$ of an inch thick. Now, supposing that is the case, how are you to strengthen your iron ships except by doubling? You may no doubt thicken the iron plates in order to obtain durability, because, if you recollect Mr. Fairbairn, under the sanction of Lloyd's surveyor, stated yesterday that in many cases the bottoms of iron ships had actually worn out, and, as a rule, in the course of a few years they had to be renewed. These various drawbacks seem to put the case in the position in which I first introduced it to you—that we are not yet entirely to cast wood on one side. I believe that in iron ships you get certain advantages, and I believe that you must accept with them certain disadvantages. In all discussions about iron ships, we have a reference, *ad nauseam*, to the *Richard Cobden* for durability, and to the *Great Britain* for strength. If you are disposed to rely upon that, I can give you a list of nearly fifty iron ships which have actually broken in two. What then are we to do? I recommend as a compromise an outside planking of wood, properly adjusted on an inside iron framing, and then we shall have a ship more durable, more serviceable, and stronger than any ship built entirely either of iron or of wood.

Mr. Bramwell, Assoc., I.N.A.: Mr. Lamport has objected to a remark which Mr. Fairbairn made hat a structure cannot be made of wood to possess the same strength as if made of iron. Mr. Lamport says this may be true of such structures as Mr. Fairbairn speaks of, but it is not true of ships. I think that proposition of Mr. Lamport's ought not to pass without remark. We know that in a seaway ships are not supported equally all over, and further, that the buoyancy of the various parts does not bear one and the same ratio to the load of those parts, so that either from the action of the waves, or from the variation of the load in different parts, ships have to act as girders, and, therefore, it appears to me their structure should be analogous to girders; and if this be so, Mr. Fairbairn's observations would apply to ships. Mr. Lamport further advances the proposition, that wood, weight for weight, is stronger than iron. By this he may mean tensile strength or transverse strength; but granting it is theoretically true of either or both, this problem arises, *viz.*, how to lay hold of wood without cutting it to pieces. Take, for example, the familiar case of a wooden principal to a roof, and examine the mode by which an endeavour is made to render available the tensile strength of the tie beam to resist the thrust of the rafters. It will be found that the tie beam is deeply notched to receive the heel of the rafter, and not only is the beam thus cut into so as

to be much weaker than its average section, but the thrust after all is merely resisted by the feeble adhesion between the parallel fibres of that part of the tie beam extending beyond the notched part—a means frequently insufficient.

About four years ago a building came under my notice, where there were several wooden truss bearers carrying a heavy load. Nearly three-fourths of these trusses had given way owing to the upper part of the wood having slipped over the lower part, and this slipping had taken place to such an extent as to thrust out of a thick wall that bore the trusses the bricks which were opposite to their ends. I cite this as an instance in which a beam might have had theoretically greater strength than an iron rod of equal weight, but which, for all practical purposes was far weaker, because its strength could not be made available, that is to say, the beam could not be laid hold of.

Further, I think that the practice of the builders of wooden ships proves that they do not look on wood as being, weight for weight, stronger than iron; as it will, I doubt not, be admitted that a wooden ship of a given size weighs more than an iron ship would if built off the same lines, while the strength of the wooden, even with its greater weight, is certainly no more than, and probably not nearly so great as the strength of the iron ship.

Mr. Grantham, Mem. Council, I.N.A.: Attempts are made to draw comparisons between iron and wood as a material for shipbuilding. I should rather contend that they admit of little or no comparison. The material taken by itself does admit of some comparison, but there it ends. The whole question in a ship rests upon the fastenings, and not upon the material. Mr. Lamport has told you that a ship with an iron frame, and wooden planking outside, may be equal or superior to one built entirely of iron. Now, he forgets that the shell of an iron ship becomes one entire plate, whereas when we put planks outside to form the shell of a ship, everything we do in the finishing of that ship tends to thrust those planks asunder. Caulking tends to stiffen a ship, but it also has the effect of forcing the material asunder—the very opposite of what it ought to be. The only thing you can do is to look to practice; and my friend on the right (Mr. Bramwell) has shewn that in practice, an iron ship, invariably, I think I may say, strength for strength, weighs less than a wooden ship. Launch an ordinary wooden ship, and see how her form will alter—launch a strong iron ship, and see what will be the difference.

Mr. Lamport: I have not said a word in favour of a ship built entirely either of iron or of wood.

Mr. Grantham: My experience in iron ships is this,—As we proceed we keep adding to the length, and by certain judicious arrangements—by making the centre of the ship strong, and the ends light—you may prolong these ships to an immense extent. Try the same thing in a wooden ship, and see whether you will not very soon come to the ultimate length the ship will bear. I believe very few have attempted to make a wooden vessel more than six times the beam for the length; but I know that iron ships have gone to sea ten times the beam for the length. The comparison of the two materials as spoken of by Mr. Lamport is out of the question. Facts are best, and I think facts shew us, beyond all question, that, weight for weight, iron is the strongest of the two when the weight is properly disposed of. If you make a weak iron ship she will break in the middle. But no good builder would do this.

I should be sorry to hear any depreciation of bulkheads. I know of three instances of ships being saved by them: they were put in by myself, and in those instances about 600 lives in all were saved by this means, so that I do cling to bulkheads. At the same time, I think they may be badly put in, and badly proportioned to the size of the ship; and in such a case, they may be injurious rather than beneficial. The

more you multiply the bulkheads the more you will protect the lives of the people, and, therefore, I do urge upon everybody connected with steamships, going as they do, into all sorts of dangers, that they should multiply bulkheads to the utmost of their power. Another point of great importance is the principle of planing the edges of the plates for the vertical joints. This is a good thing, but one most grievously neglected. The greater part of joints in iron ships are over-lapped. In these, planing is of no value; but vertical joints ought to be planed, because so long as there is any interval left between the two edges, the butt is of no advantage in itself. With regard to the shearing off of the head of the rivets, of course, if you put in a bulkhead capable of sustaining 1,000 tons, and you put in rivets that will sustain a strain of only 100 tons, it is evident that the rivets must be sheared off. Bulkheads are of great service when judiciously brought into combination with other things. When, for instance, a hole is knocked into the bottom of a ship they limit the amount of water that can get into the hold, and consequently they are great life-preservers.

A Member: I should like to make a few remarks on a point which has not yet been recorded. I believe no notice has been taken of it at all, and as several gentlemen have referred to ships generally, perhaps I may be allowed to do the same. I do not touch upon marine vessels, but upon men-of-war. My idea is, that through a blow from a broadside considerable jarring would take place in these taut iron bulkheads. A plate when fired at will often exhibit toughness upon the impact of the first shot. When the second shot is fired, you can see there is a deterioration, and with the fourth or fifth shot you will observe that the plate seems to have entirely lost its first toughness, and returned to its original state. In a man of war you want to get rid of this tremendous jar upon the plate, which causes it so rapidly to deteriorate. If we put wood behind, immediately in contact with it, it absorbs a portion of the shock, but not being sufficiently rigid and complete, yields, and the plate is broken. If we put iron behind it, we find that it is a capital conductor of vibration, the iron taking up the shock and transmitting it a considerable distance. Iron is a better conductor of vibration than wood. I conclude, as the result of my observations against the targets at Shoeburyness and Portsmouth, that we must support the plates so that they shall not deteriorate. Next, we want to get rid of the concussion, which would destroy the rivets on the bottom of the vessel. Looking at the subject in this way, I get the best condition I possibly can with my plates placed near against the iron frame, so that it shall, in a measure, take off a portion of the blow. The frames are placed about two feet apart, or more, and we want to get rid of the vibration. Therefore, if we put wood between the iron frame, as in building a wooden vessel, we shall, I think, to a very great extent, get rid of the vibration. I believe that the strongest structure we can possibly get, and the one that will stand the most hammering about, is, that which has the framework of iron, and the interstices filled up with wood.

Mr. E. J. Reed, Mem. Council, I.N.A.: I rise to make a remark in defence rather of this Institution against one remark of Mr. Lamport's. He said he had not heard one word here in favour of wooden shipbuilding, and then explained that by wooden shipbuilding he meant a combination of iron plates and wooden planks. It so happens that the Council specially requested that gentlemen building iron ships, with wooden plank, should communicate with the Institution. There are no less than ten or twelve persons building new ships with iron frames and wooden bottoms. It seems to me when we consider the difficulty of fouling—which Mr. Hay is about to enlighten us upon—that that is a very promising contrivance. I do not think that Mr. Grantham has any prejudice against a ship with iron frames, wrought iron plates, and wooden plank. I should be sorry for the Institution to be supposed to be unmindful of a

system of construction which has caused so much interest among mercantile shipbuilders. The Institution are not at all unmindful of it. The Council have noticed it in their Annual Report, and will be glad to receive Papers upon the different modes of construction of vessels of that class.

Mr. W. Roberts, Assoc. I.N.A.: Reference was made just now to the wearing out of the bottoms of iron vessels. I happen to know of a vessel which has an iron bottom, and which is about twenty-six years old, and to my certain knowledge she is in a fair condition now. With respect to iron frames and wood planking, I beg to say, that I worked upon a vessel which was built upon that principle some twenty-two or twenty-three years ago, and I think there is a vessel now running—the *Little Western*—which must be at least twenty-six or twenty-seven years old. Unfortunately, I was not here to hear the commencement of the Paper upon bulkheads, but in several cases lately I have had to put in new bulkheads, and the system I have adopted has been to use the T iron on one side, riveting each plate to it, and crossing that on the other side by means of the T iron again. By that means I can make a strong bulkhead, with less weight than in any other form.

Mr. T. J. Ditchburn, M.I.N.A.: If wooden ships be fairly and fully examined, and contrasted with well-built iron ships, there will not be a doubt as to the superiority of the iron ships over the wooden ones. Take for example, the ribs or frames of the wooden ship, from the floors to the top-timbers, and there you will find a most unconnected, grain-cut, disjointed, chunked up piece of carpentry; whereas the iron ship is, comparatively speaking, perfection in the frame-work. Each rib or frame can be made the entire length of the ship's transverse section, that is, continuous from gunwale to gunwale, and with any degree of strength that may be required. And again, take the skin or planking of the wooden ship, and you find that there is not one plank fastened to another throughout the whole structure, but, on the contrary, they are actually made to force each other apart by the driving of old rope and oakum into the interstices and ends, or seams and butts; whereas the skin or plating of the well-built iron ship has each plate securely riveted to the other, producing a uniformity of strength and durability that a wooden ship cannot equal. In 1835, I made an attempt in a wooden ship to remedy to a certain extent this weak and defective carpentry. I built a steam vessel of about 350 tons, and in her I omitted three-fourths of the frame timbers, and substituted iron diagonal plates for the same, increasing the thickness of the external planking, and firmly uniting the seams and butts, and the whole to the iron frames. This hitherto unheard-of innovation was, of course, denounced; nevertheless, it proved a complete success. The vessel which I thus constructed has run many thousands of miles at an almost nominal cost of depreciation of hull, and is yet afloat. However, I was convinced that iron, properly applied, was the best material for constructing a uniformly strong and durable ship, but the time for its adoption had not then arrived. In 1838, I obtained an order from a foreign government to build an iron vessel of 250 tons. This vessel gave the greatest satisfaction, and was the cause of my obtaining other foreign orders. But, notwithstanding these results, the prejudice at home continued, and all my efforts and advocacy were deemed by my most intimate professional friends as being the result of a mental affection. Shipwrights, caulkers, and sawyers conspired against me, and fired my premises, and burnt to the ground the finest mould-loft, joiners' shop, and storehouses on the banks of the Thames. From this yard, was launched, in 1825, the first passenger steam vessel that left England for India: she was named the *Enterprise*, and was of 464 tons, and 120 horses' power. She had a copper boiler in one piece, weighing 32 tons, which alone cost £7,000. The total expense of ship and voyage, including a supply of coal at the Cape, amounted to £43,000. The passage was made

in one hundred and thirteen days, which included two days seventeen hours at St. Thomas's, and seven days twenty-two hours at the Cape of Good Hope. In 1840, I introduced angle-iron ribs with wood planking, and in 1841 I took out a patent for planking with wood on frames composed of angle-iron bars, the frames being traversed externally by suspension plates, and internally by diagonal truss plates. This mode of building is at present in practice on the Thames, at Liverpool, at Glasgow, and in many other ports; but it does not unite together the seams and butts of the outer planking. When this is effectually accomplished, then the combination of wood and iron may stand next in order to the well-built iron ship. Very few persons beside those who have been engaged in the actual building of large ships, know the great cost and time required to procure large and suitable timber for such work. I have known the constructors of a line-of-battle ship to be compelled to wait nine months for a stern-post.

Considering the vast extent and importance of our navy, and the great scarcity of English oak, (there being at this time not more oak timber in our Royal forests than would be required to build annually one 74-gun ship), every means should be used to find an equally efficient substitute. It is a national object; and every motive, whether of safety, policy, or economy of our financial resources, should prompt us to pay the most serious attention to the subject. We have found, I maintain, a glorious substitute in iron. When we consider the vast natural resources which our country possesses, it becomes a self-evident fact, that if there be one branch of commerce more than another that belongs to England it is that of iron shipbuilding, possessing as we do an abundance of iron ore and coal, and the greatest facilities for the construction of iron vessels.

ON THE PROTECTION OF IRON SHIPS FROM OXIDATION AND FOULING.*

By W. J. Hay, Esq., F.C.S., Assoc. I.N.A., Chemist and Lecturer, Royal Naval College, Portsmouth.

[Read at the Fourth Session of the Institution of Naval Architects, March 27th, 1863; H. Chatfield, Esq., Vice-President, in the Chair.]

The suitableness as well as the great and essential use of iron as a material for shipbuilding, must render any matter bearing upon this subject of sufficient interest to bring before you. The number of years that have elapsed since my Paper on this subject was read before the Royal Society (in 1848), will be sufficient excuse for my now reading a further Paper on the same subject before the Members of this Institution, to which, I believe, the subject more particularly belongs.

The disadvantages arising from the oxidation and fouling of iron, such as the necessity for frequent docking, and loss of speed, almost led to the necessity of discontinuing its use in the construction of sea-going ships. In fact, such was the alarm felt by the Admiralty in 1847, at the formidable character of this species of mischief, that it threatened to fix a limit to the employment of iron ships for naval purposes. The Board had commenced selling, and were only debating about the entire sale of all sea-going *iron* ships, when the favourable report of the result of my applications to iron vessels—the *Undine* in particular—entirely turned the scale in favour of retaining the few, at least for experiment, and saved the splendid transport, *Simoon*, from being doomed as a prize to the Peninsular and Oriental Company.

There can be no doubt, I think, that the suggestion of Mr. Scott Russell and others, of providing docks at all the stations abroad, must eventually be carried out, as we are deriving such paramount advantages from using iron that it will probably supersede wood for the construction of ships and other vessels. The iron shipbuilder having launched his ship, leaves her in the hands of others, but the great necessity for the ship being cared for afterwards, is shewn in the casualties attending iron ships, such as are not to be met with in those built of wood. A few examples will be shewn as I proceed.

* Received March 24th, 1863.

In 1845, the Right Hon. H. L. Corry, in alluding to the great importance of iron—the produce of our own land—as a material for shipbuilding purposes, stated that two formidable difficulties existed, and that it was necessary attention should be directed to this subject, *viz.*, the oxidation and fouling of iron ships' bottoms; at the same time he observed that it would be a discredit to the chemists of this country, to say nothing of other countries, if these difficulties were not overcome.

Patents out of number, as well as some most absurd suggestions, have from time to time been submitted to the Admiralty for trial and adoption. I have tried many experiments upon plans that have occurred to me, but none have equalled oxide of copper in the various tests to which they have been subjected. Few persons who are unconnected with the Service, know the special requirements of a ship in the Royal Navy. This accounts probably for so many suggestions upon this subject.

The particulars of the first four experiments tried with the copper oxide, as appended to my Paper to the Royal Society in 1848, may interest you. The first experiment tried was on the *Rocket* in May, 1845. The results of this experiment were so satisfactory that, at the suggestion of Admiral Sir Hyde Parker, in June, 1847, she was coated zebra-like, with alternate stripes of red lead and copper oxide composition. When docked in August, 1848, she presented a curious appearance: many of the red lead patches were corroded, and had weeds three or four feet long growing to them, while the patches of copper composition, were generally covered with a little slime, but no weeds or corrosion.

The second experiment was made on H. M. Yacht *Fairy*, in September, 1845, for comparison with plans submitted by Mr. Owen, by Baron Wetterstedt, and by myself. A space 18 feet from the stem was payed with black paint prepared with arsenic by Mr. Owen, another space 3 feet square was payed with pitch, naphtha, and copper oxide chemically prepared by myself, and the rest of the bottom was payed with Baron Wetterstedt's composition.

This vessel was at Mr. Ditchburn's Ship Building Yard for alteration, &c., in January, 1847, and the late Mr. Fincham and Captain Crispin, R.N., were then directed by the Board of Admiralty to report on the state of the various compositions on the bottom. Their report was as follows:—

"We have conferred with Mr. Ditchburn as regards the application for paying the "bottom of the *Fairy*. At present there are three compositions on the bottom, one by "Mr. Owen, one by Baron Wetterstedt, and one by Mr. Hay; on the parts of the two "former oxidation has gone on very rapidly, while Mr. Hay's appears quite free from "oxidation, and the only defect we perceived in it was that of its partially flaking off,

" which we considered was occasioned by its being put on the bottom while in a damp " state. This would be remedied we imagine by the bottom being heated during the " operation of applying the composition. Mr. Hay's plan appears to be based on pure " chemical principles, as the pitch varnish he applies forms a non-conducting medium " between the iron and the metallic substances applied in the second coating, which second " coating gradually decomposes and prevents the adhesion of any animal or vegetable " substance. We beg, therefore, strongly to recommend to their lordships that Mr. Hay be " directed to prepare the bottom and pay it over with his composition, taking care that " every precaution is observed to ensure its being put on properly. To effect this " desirable object, we beg to submit that the *Fairy's* bottom be not touched until her " return to this port, when we propose to place her in a dock in this yard, and give this " very important subject a good and complete trial under our own immediate inspection."

The third experiment was tried on H. M. S. *Undine*, in May, 1847. The reports of the Commander-in-Chief and the shipwright officers of H. M. Dockyard, Portsmouth, were so satisfactory that the idea of selling the iron ships which were then in the Service was abandoned. These officers reported as follows:—

" 27th October, 1847.

" Having yesterday laid the *Undine* on the graving slip for the purpose of examining " the state of the bottom, we beg to report that we found the starboard side, which had " been prepared with red lead, very foul with grassy weeds and slime, under which a " thick coat of oxide had generated, whilst the port side which was prepared with " Mr. Hay's composition was perfectly clean, with here and there a few spots of oxide " where the composition had been rubbed off.

" We beg to add that the *Undine's* bottom was prepared for experiment on the 12th " May last: the vessel was subsequently laid aground for examination on the 21st June, " and again on the 7th August, and on each occasion the same result in favour of " Mr. Hay's composition appeared as now presents itself. We would observe that the " starboard or red lead side was cleaned at the periods mentioned, and has now been " cleaned again for the third time, whilst the port side has remained untouched since it " was originally covered with Mr. Hay's composition.

" From the very striking results, therefore, of this application, we would suggest that " the *Undine* be taken into dock at a convenient opportunity for the purpose of removing " the red lead and applying Mr. Hay's composition to the whole of the bottom."

The fourth experiment was on H.M.S. *Recruit*. In April, 1847, the copper oxide preparation was put on the port side, and charred boiled linseed oil and red lead on the starboard side, except a space midships 4 feet square, on which the oxide of copper preparation was applied. On examination, after her return from the Tagus, the port side

had no adhesions whatever, except about one dozen small barnacles: the starboard side, except the 4 feet space amidships, was, on the contrary, covered with bushels of the *Lepus Anatifera*, or duck barnacles, long weeds, as well as innumerable clusters of other animalculæ.

My attention has been frequently directed to this subject, and all kinds of pigments have been successively tried, but not one has, up to the present time, in any way answered the purpose, or approached the oxide of copper in its suitableness as a material for preventing the fouling of ships' bottoms; in fact, in all competitive trials, and there have been a great number with different materials, the copper oxide, when properly applied, has in every case taken the palm. With respect to protectives for the iron, much is yet to be done, and although the most suitable materials are at command, yet the imperfect application, in many cases, prevents their use.

One of the best protective applications is red lead. It is true that this has occasionally failed, but its failure has resulted from its improper application, and not from its being an improper material: this alone will justify a statement that has been made of the reduction of the red oxide to its metallic state. Theorists have stated this to be impossible, but practical men have seen it, and are able to account for it.

The next best materials for protecting iron, and which are far superior in that they can be used with advantage when red lead cannot, are the waterproof glue, and a varnish of foreign asphalte and mineral pitch, dissolved in rectified naphtha; but these require attention to the quality of materials and application, as does also the red lead. The advantages which these possess over red lead are, that thorough dryness of the bottom and the lengthened time to dry and harden are not required as in the case of the latter. I have seen some coatings of red lead in winter time in a damp dock, that have been scarcely dry after three or four weeks: sometimes ships which have been undocked after the application of several coats have caused a red train to follow them in the water, from the paint not being hard. But where red lead has shewn itself so advantageous is in cases where it has been of good quality, and a very thin coat has been applied during the building of the ships, by which means it has gained time for further oxidation of the linseed oil, and formed a coating, firmly adhering to, and as hard as the iron itself. Many instances are on record where, after ten or twelve years, and with ten to twenty new coatings of various compositions, and sundry scrapings, the original red lead, applied during the building of the vessel, may be seen tightly adhering to the iron.

The basis of the anti-fouling preparation which I have found so successful, and which for many years has been used in H. M. Service by my recommendation, is sub-oxide of copper. The oxides of copper used for this purpose are the scales separated from sheets of copper in the pickling process, after they have been rolled: these scales

are principally sub-oxide of copper, with a small proportion in the state of per-oxide: they are very pulverulent, and require little labour to bring them into a very fine powder; and they are prepared for application by being mixed with a varnish made of vegetable pitch and rectified naphtha.

It must be thoroughly understood that the protective coating when used with the oxide of copper anti-fouling composition, is not intended merely to act as a non-conducting medium to prevent galvanic action, but to protect the iron from chemical action, resulting from the action of air and sea-water on the iron. This action appears to be little understood, judging from printed statements which occasionally appear, stating that the loss and corrosion of iron is due to galvanic action of copper preparations. In this enlightened age it does not require a conjurer to shew how copper preparations act when brought into contact with iron: we know that a knife dipped into a solution containing copper, or even into some highly coloured pickles, becomes coated with copper (metallic copper), apart from theories, and the results of laboratory experiments with the constituents of sea water as substitutes for the sea itself. It may be remarked here, that a wide difference exists between results obtained with the constituents of sea water, and those obtained with natural sea water.

I have illustrations which shew the deposition of lead, barum, zinc, and copper on iron by its remaining in contact with the oxides of these metals in sea water, and a deposition of the muriate of iron and magnesia, on iron placed in sea water alone; but it must be understood, that these substances had no protective material insulating them from the iron. In these cases, chemical action is set up, and the chemical forces of the different substances are exerted on one another: decompositions take place, and electricity is given off: different electric polarities are set up, and the current arranges the deposit of metal on the iron. It is admitted that in chemical decomposition heat is given off or absorbed: now, this heat is due chiefly to electricity, and much depends on the electrical polarity of the different elements during chemical action for the character of the result; for it is my belief that no overthrow of perfect chemical combinations can take place without a change of electric polarity resulting therefrom. The instances I have observed of the reduction of red lead to its metallic state are very few, and these were where the red lead had been used as a putty more than as a paint, and where to gain hardness, the oil had almost been got rid of. One instance was in the extreme end of the blade of the iron screw of the *Himalaya*, where the air holes in the casting had been filled with red lead putty. I have occasionally seen it around rivet heads, where they, no doubt, have been previously seen to leak: the red lead has been rubbed in with the water until it formed a paste with it, excluding most of the oil. The sea water and iron would, in these cases, have the power of reducing the lead to its metallic state; but I should be

sorry to sacrifice the use of red lead at the shrine of these isolated facts. I repeat that I have seldom observed this result, although in my official capacity I have had to examine, and report upon a great many ships coated with red lead.

With respect to the assumed theory of some persons, of the action of the oxide of copper used in the anti-fouling composition, I must give an *entire denial.*

I will next refer your attention to the case of the *Sharpshooter.* She was built in 1845, and the number of vicissitudes that she has been subjected to, shews the value of iron as a material for shipbuilding. In 1846, she was payed with red lead, and afterwards with Parker's black varnish. In December 1847, my composition was put on her port side, and Chanter's on the starboard. In April 1848, from the corroded state of the starboard side, it was necessary to dock her to remove the composition and replace it with mine, that on the port side being hard and firm, and without oxidation. In August 1848, she was run into, and required a new stern-post, &c.: in December 1848, she ran aground; and in December 1849, she was docked at Malta. An extract from the Commander's letter will best explain her state. He said:—

"When the *Sharpshooter* was docked at Malta, your composition had been applied "about fourteen months. We found weed of about 6 inches in length covering her "bottom, but adhering very lightly to the surface alone, for it had nowhere penetrated "into the composition. In fact, it might all have been removed by canvas rubbers, as "might also the very few and sickly barnacles which were growing with it. We were "directed to remove every particle of the composition, as it was considered that the coal "tar with which we replaced it would not act properly if any remained. It was, however, "a difficult matter to do so, for it was almost as hard as the metal itself, and adhered as "tenaciously as if it formed a portion of it. We could neither scrape it off, nor scale "it off by hammering with a blunt instrument, but were obliged to pick it away by "striking with the scraper points. The iron underneath was as good as new, without "the slightest symptom of corrosion or even discoloration. I assure you, I was very "sorry to see it removed, for I consider it had proved *most admirably* successful."

In addition, the evidence of the engineers of the *Sharpshooter* was, that this vessel's bottom was not so foul in fourteen months as were those of other vessels which were payed every six weeks at Malta with other substances.

In November, 1851, the bottom, which had been coated with mineral tar, was found loaded with muscles, barnacles, and oysters, from six inches to one foot thick. The bottom was corroded to a considerable extent, from the tar having entirely perished. The decomposition of animal matter which takes place whilst attached to the bottom is most destructive to the iron. In December, 1851, she was scraped, and payed with two coats of protective varnish: after remaining in the basin to receive new boilers, she was

again coated in November, 1852; and she remained in Portsmouth harbour till October, 1856. She was payed again in October, 1857, and then went to the west coast of Africa. After remaining nearly two years on that station, she was, in June, 1859, hecled over, and after being scraped as low down as possible, she was coated with another kind of composition. In January, 1860, at Ascension, the same treatment was adopted: again, on the 10th June, 1860, at St. Paul's de Loando; and a fourth time, in February, 1861, at the same place, as none of my material could be obtained on those stations. In July, 1861, she arrived at Portsmouth, with her bottom covered with oysters and shell fish. She remained in the harbour in her lightened state, with these decomposing on her bottom, till September, 1862, and when she was docked and the oysters removed, the iron on the bows, the run, and in all parts where she had been scraped and payed with the other composition, was found to be very thin; whereas the bottom plates that could not be got at to receive the same treatment as the other parts were most of them after five years' wear in excellent order, neither the rivets nor the plates being injured, and the oxide of copper composition being hard and firm thereon. Facts are stubborn things, and I leave it to you to judge in the above instance how far it was galvanic or chemical action.

I will now give you a few examples of other vessels, so that you may compare the results with those obtained with the *Sharpshooter*. Although she was badly treated, her state was not worse than might be expected when compared with other iron vessels not coated with composition containing oxide of copper, on the Coast of Africa, where the destruction of copper sheathing is also very rapid.

The *Antelope* was undocked at Portsmouth in April, 1852, and on her return in July, 1853, she was again docked: more than 6 tons weight of barnacles, &c., were then removed from her bottom, the iron was much corroded, and it was necessary to remove many of the rivets. The *Harpy* was docked on the 8th December, 1852, after having been about four years on the S. E. coast of America: her bottom was covered with a thick coating of barnacles, other shell fish, and weeds, and it was much oxidized, flakes of oxide of iron from 4 to 6 inches in diameter, and from $\frac{3}{8}$ to $\frac{1}{2}$ an inch thick, being removed: it was also necessary to shift a number of rivets which had become defective. The *Jackall*, which was docked at Portsmouth in April, 1848, had been coated with red lead at Devonport in May, 1847: when she was docked the bottom was exceedingly foul with barnacles, oysters, &c., and on scraping the iron plates they were found worn to such an extent as to make it necessary to punch holes and plug them. There were 150 defective rivets removed from the starboard side, and 50 from the port side. In the case of the *Grappler*, which was ordered to be built only in July, 1846, the bottom plates were so bad in June, 1849, that a hole five inches in diameter was

discovered while she was at Madeira; and in consequence of the report of the officers in October, 1849, the Board of Admiralty determined to sell her rather than effect the many repairs necessary.

I may state that the *Fairy* yacht has been payed on my plan up to within the last year, and although not built with any particular care as to the quality of iron, she has done good service, and is in a very good state now. One of the iron fire floats at Portsmouth Dockyard has been coated from time to time for the last fifteen years with my application, and she is now in an excellent state of preservation.

The following is an extract of a letter which I received from Mr. Henwood, while he was master shipwright of Malta Dockyard, at which place a comparative trial of compositions had been made on the bottom of the *Caradoc*.

"A more fair and perfect trial of the two compositions could not have been made—"every one here says the same—and a more decided result showing the superiority "of your composition over the other, could not have been more unquestionably obtained. "I just mention this as the broad fact of the case which I have duly and circumstantially "reported in the usual official manner. No pains were spared to make the experiment "fair and decisive, and I have the pleasure to add my congratulations on the subject."

The following is an extract of a letter from Captain Hire, R.N.:—

"28th December, 1862.

"H.M.S. *Urgent* was coated with your composition at Portsmouth, in December, 1859, "and on her going into dock at Aberdeen, near Hong Kong, on the 29th January, 1861, "the bottom was found to be perfectly clean and clear of all shell fish, &c., the surface "being merely covered with a slimy substance; on the removal of this by a slight "scrubbing the composition remained in many parts quite perfect and the ship was in "excellent preservation."

One great difficulty has existed since the first use of the copper oxide, *viz.*, that of requiring great supervision in its application, for when the varnish is made too thick the oxide becomes locked up, and much of its usefulness is destroyed by its not coming in contact with the sea water. When the varnish is made too thin, the oxide, by its great density, sinks to the bottom of the pot, cask, or vessel it is in, and unless the composition is continually stirred while it is being applied the oxide is left in the pot or cask, and does not go on the bottom of the vessel: this will account for some of the disappointments complained of in using this material. I have tried many methods of increasing the power of the varnish in a thinner state to suspend the copper oxide during its application, and one of the best methods was the addition of pure creosote. I have now most completely succeeded in overcoming this difficulty, and insuring with

certainty its uniform effect, at the same time doing away with any more supervision than necessary for ordinary paint; but finding myself considered an inventor rather than an adviser, and in consequence of the little credit I received for my former communication to the public, of the composition best suited for iron ships, I have been induced to patent my present plan, which is new to the scientific world. It establishes a theory which has been objected to,—that linseed oil, on being boiled with oxides of lead, and other metallic oxides, does obtain oxygen therefrom; but whether the whole of the oxygen is taken up by the oil, or a portion of hydrogen escapes from it to combine with the oxygen given off, the fact is established that a certain amount of oxygen leaves the metallic oxide. The plan I adopt is to take the puce-coloured or sub-oxide of copper and roast it till it takes up another equivalent of oxygen, and is converted into the black oxide. This oxide is then boiled with linseed oil in stated proportions until it assumes its original puce colour as sub-oxide, the linseed oil, at the same time that the colour is gradually changing from black, increases in consistency: it is tested from time to time by dropping it into water, when it is proved by the colour of the oxide, and the change in the state of the oil keeping steady pace with each other.

The oil so treated becomes a quick drying oil, and is capable of suspending a large amount of copper oxide, even when made thin by turpentine, or any other spirit. It may be packed in casks for any length of time without separating: it answers equally well over red lead paint on plain wood, or on any kind of varnish, and in proportion to the time a ship is required to remain out of dock or on a foreign station, the paint may be suited within certain limits.

With reference to the theory of the action of the oxide of copper when applied to a ship's bottom in varnish or oils, the constant action of the sea water upon the surface of the coating continually removes a portion of the varnish, and exposes the facets of oxide of copper, which being in the most favourable state for combination with the chloric acid, an oxichloride is formed, and is immediately removed by solution in the water, leaving no oxide to act galvanically on the iron; and from the rapid removal of the oxichloride of copper, the adhesion of animal or vegetable substances is prevented, and in a similar manner the most durable copper sheathing is kept clean. This is not occasioned by the poisonous effect alone, for although some delicate animalculæ and weed are affected by it, or by the sudden contact with salts of copper, yet many shell-fish such as muscles and oysters adhere to it, and are found in a healthy state. These fish, nevertheless, are prejudicial to those persons who take them for food.

I contend that the copper oxide has no more to do with the decay of the iron, or even the abrased parts, than any other preparations. We have seen that the *Himalaya*, which has frequently been coated twice a year, after being out two months was so

much oxidated as to require re-coating: not only was no copper preparation used, but she had an iron screw-propeller instead of a brass one. The *Megæra*, to July, 1852, had been coated at four different periods in two years, and the iron plates were at that date so much deteriorated, that I declined to apply my composition until the master shipwright had caused a sketch to be made shewing the state of the bottom. No copper application whatever had been used.

The properly prepared copper oxide paint cannot act as a galvanic agent, as every particle of oxide of copper is insulated by the oil or varnish in which it is enveloped; and unlike preparations of a metallic character which have been frequently tried, and found to require oxidation previous to combination with chloric acid, the oxide of copper is, as soon as it is uninsulated, ready for chemical combination with the elements of the sea water.

A table, shewing the deflections by the galvanometer, establishes the fact that no serious galvanic action is produced by the anti-fouling composition. In my patent for anti-fouling composition, I included the application of zinc plates inside and outside of the hull of the ship when desirable, to prevent oxidation from abrasion or other causes, to meet the apprehensions of the timid, and the objections raised by the alarmists.

While alluding to galvanic action, I will mention an interesting result of some experiments carried out in the chemical department at Portsmouth, by direction of the Admiralty, from attention being drawn to this subject by an engineer of the Royal Navy. The galvanic action produced by the copper sheathing of the ship and the iron boiler (the connection being made by the communication of the brine and feed pipes from the boiler to the outside of the ship), was found to be very little while the water was hot, but greater when the water was cold: the less the density the greater the deflection.

The galvanic pairs existing in iron ships where insulation is not perfect are very numerous: the different qualities of sheet iron of which some ships are constructed, the different states of the same sheet, the rivets, the angle-irons, the metal valves, screw propeller and framing (there being nearly a mile of copper tubing in some such vessels as the *Warrior*), render chemical supervision very necessary. Without galvanic pairs, if the inside is not properly protected, chemical action is readily set up by sea water coming in contact with the iron, as when iron is either in contact with, or in sea water it oxidates. The oxide when first formed is soft, and is electro-negative to the iron. If on the inside of the ship this oxide hardens, and forms a scale of oxide, which still increases the rate of corrosion: if on the outside, and the ship continues long at rest, the oxide hardens into scale, and increases the corrosion by galvanic action; but

if the ship is kept in rapid motion the soft oxide is swept off as fast as it is formed, and the exposed surface of the iron when first examined presents a clean and apparently uncorroded appearance, which too frequently deceives inspecting officers who are not accustomed to witness the chemical changes which take place with iron. The different conditions under which the ship *has* been, and *is* at the time, are not taken into account, and hence the extraordinary reports and recommendations which are sometimes made. From these remarks, it will be seen that the real loss is less while a ship is kept in motion than when she is at rest, and hence her tendency to foul less while in motion than when at rest, either in fresh or sea water when not coated with any substance.

What is required to stop chemical action, and also to arrest the galvanic action set up by the presence of substances in different electric states, is to thoroughly coat the iron with an indestructible varnish or paint, both inside and out. When, however, the action is energetic, owing to the galvanic pair being uninsulated, in the insulated state they cannot affect one another. The mere tyro in electro-chemical science must know that contact must be perfect to produce galvanic effects: and any one conversant with the chemical effect produced on iron by the atmosphere and moisture, or pure water, will be prepared to understand the chemical effect of sea water containing many elements in different electric states ready to change their state and cause the destruction of the iron. In many instances of undocking vessels which had been coated, the shores removed the composition, and exposed the bare iron, when, if the alarmist's theory held good for one moment, these bottoms must have been perforated at each of these places. One yacht when purchased into the Service had been so long laying in a strong tidal stream, that at the water-line, and on the bows, it was suggested that eighty plates should be removed; but Mr. T. Miller, now chief engineer at Keyham, had formed so good an opinion of my preparation, that he determined to try it first, and removed only about six or seven plates. The result is, that a great portion of the condemned plates still remain in the bottom after fifteen years' service: they have been continually kept coated with my composition. It is well known, that in proportion to the character of the water, chemical action will take place: fresh water produces less action on iron than sea water, and foul water, or that impregnated with sulphuretted hydrogen, such as is found on the coast of Africa, rapidly destroys, not only iron, but also copper sheathing. It is from the effect of this foul or bilge water that much of the damage is done to iron ships inside. The continual wash of the bilge water which is an agent of great corrosive power, more especially near the boilers, causes immense damage from want of due protection on the inside. The bilge water when in motion removes the oxide as fast as it is formed, and imbibes a large quantity of air, whereas, if the vessel is properly coated inside, this cannot take place; and if filled with waterproof glue and light bricks, and a

level surface formed, the whole of the water would be effectually removed with fewer pumps.

There are numerous parts of iron ships of war that require chemical supervision, and not only should every metallic fitting which is electro-negative to the iron be insulated, but every piece of timber should be insulated, especially in the bilge, for when wood decays in contact with iron and sea water, it produces sulphuretted hydrogen. Certain kinds of wood, such as teak, and stinck wood, are less liable than others to decay when brought in contact with iron. The injury by the combined action of wood, iron, and sea water, induced me from the state of the armour-plate bolts of the *Meteor's* battery to propose to the Board of Admiralty in 1860 that sheet zinc, instead of felt, should be placed between the iron armour plating and the wood, and that the bolts should all be galvanized: the state of the *Warrior*, *Resistance*, *Defence* and *Black Prince*, when docked, all proved the desirability of this plan. The Waterproof Glue Company have succeeded in having a trial made of their glue for this purpose, and its elasticity and adhesive character were fully tested upon one of the iron plates on the experimental target before it was ordered to be adopted for the armour plates of the *Royal Sovereign*, the *Royal Alfred*, and the *Ocean*. The appearance of the *Meteor's* armour bolts at the junction of the iron and wood was similar to two cones joined at their tapered ends.

Salts of copper, sulphates, and oxychlorides, of which so much has been said, do injure the iron, the acids being easily obtained from them when in contact with iron by the greater force of the iron for the acid. Applications constituted principally of grease or tallow require no poisonous materials, as will be seen if the theory be practically carried out, but some most extraordinary experiments have recently been sanctioned and carried out, with mixtures of grease, &c., thinned down with train oil as a top dressing, which, as might be fully expected, destroys the original and durable coating of red lead, and in a short time it requires renewing.

I may mention a very curious fact connected with oxide of copper paint or varnish, that none of the testacea penetrate it when they form on it. When the vessel is passive from remaining in harbour with weed and decomposed matter flowing against it, barnacles, &c., attach themselves, but never penetrate through to the iron or wood, as they do with most other applications.

In conclusion, I must allude to the statements made respecting the foulness of the *Warrior's* bottom: after being out of dock nine months (out of this period she had been in the Hamoaze six or seven months, where copper ships foul in this time), she had no oxidation on her bottom, although coated with the greatest expedition to go to America, where it was thought that her services might be required in September, 1861.

DISCUSSION.

Mr. Peacock, Assoc. I.N.A.: It being so late an hour I will be as brief as possible in my remarks. The subject is a very interesting one, and particularly so to me. I have listened with great attention to Mr. Hay in describing all the stages of trials he has been making for many years in his preparation of copper, and he seems, in his own opinion, to have arrived at a most satisfactory result, as to having overcome all the galvanic action consequent upon bringing copper and iron into juxtaposition, under certain circumstances. When I first entered upon the subject of keeping ship's bottoms clean, some twenty-seven years ago, I began with copper. I used oxide of copper, sulphate of copper, arsenite of copper, and powdered copper itself, and found that so long as I could isolate the copper entirely from the iron it kept clean, and free from oxidation, but the moment I removed a portion of the preparation, and exposed the surface of the iron, I found that at that spot the iron became eaten away. Mr. Hay states that galvanic action cannot ensue, and that the copper is converted into an oxychloride which does not act upon the iron.

Mr. Hay: Does not remain to act upon the iron.

Mr. Peacock (continuing): Mr. Hay's argument went to prove that oxychloride of copper had no effect on any exposed portion of the iron in its vicinity. I would not profess to state my knowledge of chemistry, or put it against that of Mr. Hay; but as a practical man who has made the subject his study, I think, at least, I may offer my views and experience. I made several trials in the Pacific, when I went to South America in 1840. I caused sulphate of copper to be ground into fine powder and converted into a pigment. I found that it kept clean to a certain extent, but wherever there was any abrasion in the surface and undercoating, there so certainly the iron became eaten into and oxidized; so much so that I almost despaired of being able to make copper available at all. In 1847 I returned to England, when I began *de novo*, and meeting with the same results, I gave up copper altogether in despair, at the very time when Mr. Hay began to take to it, and he has certainly shewn us to-night in his very elaborate and interesting Paper, that he has been very successful in having prevented this galvanic action by keeping the surface intact. He alluded to the *Himalaya*, a ship built by Messrs. Ditchburn and Mare, I think in the year 1848 or 1849. Now she has had nothing on her but red lead, as an undercoating, and for an anti-fouling coating, a composition which I invented after having given up copper. I examined her myself with Captain Seccombe, in Portsmouth, some five or six months ago, and the captain declared, and made his report to the Admiralty to the effect, that there was not a rivet or plate in the slightest degree injured upon the whole of the ship's bottom. I examined this ship thoroughly myself, and I can safely affirm that such was the fact. Of the preparation which I allude to, I will give you as brief an outline as I can. Finding after numerous experiments that no mineral substance *per se*, would answer the purpose of preventing incrustation and fouling, I applied to my fishmonger; that is to say, I prepared a large quantity of the scrapings from the backs of fish—an accumulation of nearly 1 cwt. I analyzed this, and found out the elements or ingredients of which it was composed, and the component parts of which ingredients I determined to try in a preparation with a simple metallic base as a pigment, over red lead, upon an iron ship's bottom. This was in the year 1847. I was appointed dock-master at Southampton, in the year 1848, and made my first experiment on a sea-going iron ship of the Peninsula and Oriental Company upon a single plate, then upon a surface of 3 yards square; and next, upon a quarter part of a ship's bottom, which ran several months in competition with red lead and other preparations then being tried. Invariably the plates coated with this composition were found to be quite clean, whilst those coated with red lead and other preparations had weeds 8 or 9 inches long, hanging down

in patches, during a single voyage to Alexandria. I continued my experiments from time to time, until at length the superintendent gave me permission to do the *half* of a ship's side, and after that I was allowed to do the *whole* of one side ; and these experiments were put into competition with other ships going similar voyages with other preparations. The composition which I prepared succeeded so well that the Peninsula and Oriental Steamship Company adopted it for their ships, and when the Pacific Steam Navigation Company were about sending iron ships to the Pacific, they also adopted it, and have used it ever since—a period of fourteen or fifteen years. These vessels have run for that time without ever docking in the country. They merely lay aground about every six or seven months: they are then scraped down, and recoated in two tides. There is a small amount of slime, and a little weed found upon the surface about the deep-load line; but they have no docks to go into, except a tidal harbour at Tobago in Panama Bay. One ship—the *Indus*—belonging to the Peninsula and Oriental Company has been running for fifteen years, and her bottom is pronounced to be as good as it was the first day she was built. Mr. Ewart, the honorable member for Liverpool, stated in the House of Commons a short time since, that the *Indus*, when she was examined by Lloyds' surveyors, in the docks, had not a single defective plate found in her. I was down under her bottom examining her myself, but nothing detrimental to the plates was to be seen. During the fifteen years of her arduous service in the Mediterranean and the East Indies, she never had anything on her but red lead and my composition, known as Peacock and Buchan's. This I mention as a fact, to show that there are ships which have been running for fifteen or sixteen years with their bottoms as sound and perfect as they were the day the vessels were launched. Her Majesty's ship *Himalaya*, as I before stated, has her bottom perfectly sound; but, unfortunately, there are some of Her Majesty's ships in a different condition. I will not say from what cause, but I merely speak of the fact, which cannot be denied. There is the *Triton*, which, after having been continually coated with copper ——

Mr. HAY: I beg your pardon, she has only been twice coated with copper preparation, and the rest of the time with Peacock and Buchan's preparation. Seeing that statement in the newspapers, I applied for the reports by the Admiralty, and have them by me.

Mr. PEACOCK: At all events, she had on a preparation of copper when last examined in dock.

Mr. HAY: After having been on the coast of Africa for how long?

Mr. PEACOCK: I cannot say. Here is a specimen of the oysters from the bottom of the *Triton* (exhibiting oysters 4 inches in diameter), and when these oysters were scraped off, the scrapers actually went through the iron, which in some places was not thicker than writing paper, and the flakes of rust or oxide of iron which came off were $\frac{3}{8}$ of an inch thick; and they contained particles of pure copper.

ON THE EDUCATION OF NAVAL ARCHITECTS IN ENGLAND AND FRANCE.*

By J. Scott Russell, Esq., F.R.S., Vice-President, I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 28th, 1863; the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

In the buildings connected with our great naval dockyard and arsenal, at Portsmouth, there may be seen by the visitor a somewhat considerable building of the architecture of the early part of this century. If you have remarked it, you were probably informed that it was erected fifty years ago at a cost of £35,000. On enquiry into its use, you find that this large building is the dwelling place of two modest officials, who can be scarcely said to occupy it. These officials are a clerk and an accountant, and from their tenancy the Admiralty derives a revenue, in the shape of rental, of £60 a year. This building truly typifies and represents the condition of the science of naval architecture, as it exists and is promoted by the Government of great naval England; and it truly represents also the provision which our nation makes for the continual supply, generation after generation, and for the education of a race of naval architects worthy of the English name.

The building in question is the Royal College of Naval Architecture. It represents, truly, naval science turned out of doors by the British Admiralty. It represents the naval architects of the nation expelled from their only seat of professional education, driven from their only source of scientific knowledge. It represents their vacant place taken by red tape, routine, and pennywise economy. It represents naval architecture in the dockyards reduced to the position of a humble clerk—of a mere keeper of accounts of wages and materials; and a profession the victim of the humblest economies and the most paltry savings. It is the monument of a mutilated profession, holding up in sight of the British public the stump of its right arm.

There is another monument, similar, less obvious, but nearer where we stand. There used lately to be a part of a large building in London to which we could take the foreign naval architect, and point out to him the last refuge of our destitute profession.

* Received April 2nd, 1863.

There we could show him if not principles of science, at least precedents of practice. There was a model room, almost a museum, in Somerset House, paltry indeed in comparison with those of any other country, but one in which we could point out and explain to him the peculiarities of the structures which had given to the fleets of England their known peculiarities; but this collection of precedents which embodied the principles of practical science is now also a type of the condition to which naval science has been reduced under our present Admiralty. It has been cast out of its fair rooms, it has been thrust down into a cellar, shut up in the dark, and is now effectually kept out of sight.

Thus in England we have at the present moment professional science and education expelled from the navy, and professional precedents and principles locked up in a cellar of Somerset House.

I will now ask you to follow me on a little excursion which I made across the Channel, for purposes not foreign to the interests of the English navy, and of English naval architecture. Times have been a good deal changed of late in one respect. Naval architects, surveyors of the navy, ministers of marine, great admirals, and great naval commanders, used to come from all parts of the world to Portsmouth, and Plymouth, and Chatham, and Woolwich, to search out and inform themselves in all that was most admirable in the design, construction, armament and equipment of ships of war. For some few years that has ceased, and men have gone to Toulon, and L'Orient, and Paris, to see the progress, and learn the principles of construction of the most famous, and most powerful modern fleets of war, and there you now meet men of all nations assembled for that purpose. Even English Controllers of the Navy, and Lords of the Admiralty are found to pique themselves somewhat on "having been "to France," and seen how they managed things there; and some of them have even been known to scrape an acquaintance with M. Dupuis de Lôme, the French constructor in Paris, and quote his authority as to the code of construction for the English navy. I, too, have been in Paris, and request you to follow me there for a moment. My errand was to find out how things had come to this pass—that naval architecture was getting squashed out in England, and was being rapidly developed in France; and that which had been mysterious before soon became simple and plain. A very eminent professional brother there conducted me straight to the source of some of this distinction, and the secret of some of this rapid progress in France.

My friend conducted me, where I wish you to follow me, to a handsome palace in an agreeable quarter in Paris. We entered a large court-yard surrounded on three sides by a range of roomy and comfortable, though not costly buildings. It was the School of Naval Architecture. I entered and found installed in this school, and at the head of

it, the eminent M. Reesch, whom all my life I had known through his works, and heard of from his pupils as one of the most eminent of naval architects, a good mathematician, and an eminent man of science. He had occupied a distinguished position in one of the dockyard colleges, and not long ago had been transferred to Paris, where this college of naval architecture had been established as a central point for pupils from all the dockyards of France. In this building there are all the means of an admirable education conveniently, but economically provided—there are excellent lecture rooms for the professors—there are study rooms for the pupils—large rooms with excellent drawing tables, one for each student, where under the eye of competent naval architects and engineers, they make drawings, perform calculations, and produce designs; and there is an excellent library, a large collection of drawings of precedents, and above all there is rapidly being formed and filled, a model room of naval structures of every kind.

To shew the result of this school, and the manner in which its pupils are appreciated in France, I have only to say that so great is the demand for these trained naval architects, and so highly are they valued, that they can hardly be permitted to complete their third year of instruction, so great is the demand for their practical services in the dockyards, and not merely in the dockyards, but their best pupils are to be found managing the largest and most prosperous engineering and shipbuilding establishments of France.

I have now shewn you a type of the condition of naval science in France—the consequences of having the dockyards filled with such trained men, who combine all this professional knowledge with continual daily practice—and I ask you to return once more and look at the ruinous state of professional affairs in England.

The history of the School of Naval Architecture in England is soon told. It was established in 1810, because it was found by the enquiries of a Special Commission, that although the sailors of England were better than the sailors of any other country, yet that the ships of England were in every respect inferior to those of other nations. Established in 1810, it was abolished by Sir James Graham, in 1833, because its pupils advocated the cause of science and professional skill as opposed to the empiricism which at that moment took possession of professional power in the navy—an empiricism which pretended to despise the laws, the method, and the principles of science, but which soon met the usual fate of being trampled out by them in turn, and extinguished. For more than twenty years this school sent out men fully armed with all the science of their day; but so far was the Admiralty from desiring their services, that although forced by the country to educate them, they refused to employ them, and they were denied promotion and even occupation. It was not till 1842, that they were permitted to exercise their vocation of even suggesting, advising and making designs for new ships. Messrs. Creuse,

Chatfield and Read, prepared their designs of three classes of ships, and prepared also a report which is in many respects a model of systematic naval architecture as it existed at that date. Their report does honour to the school which bred them: it showed what scientific education could do, because, although it was their first attempt, and although they had not been allowed to acquire any previous experience, by designing ships that were actually built, their vessels obtained with certainty and precision every condition for which they were designed; and although it has been objected that these vessels were deficient in the one quality of high speed, yet it must be remembered that no principle had gained general assent, or could be considered as fully established in their time, by which the quality of speed could be obtained with certainty, and without the sacrifice of any other good quality. I am warranted, therefore, in saying that the School of Naval Architecture fulfilled its intentions, that its persecuted and neglected pupils did full justice to their education, and that after the empiricism which oppressed and displaced them, had broken itself to pieces against the laws of nature, these despised pupils were found to be the only people capable of restoring naval design to the rank of a science of certainty and precision. And at a critical moment when the whole navy of England had to be transformed from a sailing fleet into a steam fleet, it was most fortunate that England was able suddenly to lay its hands on a class of men of good education and matured minds, whom the Admiralty were compelled by public opinion, and much against their own will, to employ; and in whose hands the transformation was speedily, effectually, and creditably accomplished.

By accomplishing thus creditably the transformation of our fleet or the construction of our steam navy, the pupils of the School of Naval Architecture richly repaid the country the expenses of their education, and they also discharged with equal fidelity and success their obligations to the profession at large. There are two obligations, which to my mind are imperative on every professional man who attains to a mastery, and practical experience in his profession. The first is to contribute to the common stock of knowledge whatever valuable information he may possess, that may tend to the advancement either of the principles of its science, or of the methods of its practice. Professional science, method, and skill are the common stock and inheritance of the profession. It is our working capital and our bank. We may all use it, and happily it grows in the usury. We borrow the thoughts, the knowledge, the skill, the discoveries, and the inventions of each other, but we ought to pay back the loan, and every man who truly values his standing in the profession, will feel it a duty to put himself even, by replacing his debt, and if he has anything which he has not borrowed, by making a gift of that to the professional commonwealth. The pupils of the School of Naval Architecture discharged this professional debt, by the publication of a series of Papers on

Naval Architecture, forming four volumes of professional tracts, which were for a long time the sole records of the science of Naval Architecture in England. It was the solitary student's light at the window which alone showed that poor, sick Naval Architecture was not yet dead; but this light, as I have said, became extinguished. There was no longer any knowledge taught in England which pretended to be naval architecture: nevertheless, the students of naval architecture did not forget the other debt which such students owe to their *alma mater*. There is no professional man who does not ardently long, that when his career of active usefulness has been accomplished, and he has gained the right of honest service and good work, to retire into peace and quiet, that he may see himself succeeded by a man possessing greater knowledge, higher skill, and better training than he had the good fortune to enjoy, and who does not wish to contribute all that lies in his power to the success and advancement of the race that is to succeed him.

No sooner did the School of Naval Architecture rise into power, than they commenced the agitation of the educational question, and at the same time that they commenced the designs of their ships, something was done though only on a very small scale proportioned to their limited power for the advancement of professional education. In 1844, there was founded once more in Portsmouth, a central mathematical school, called the School of Mathematics and Naval Construction. In 1843-4, the Admiralty opened schools in the several dockyards, conducted at the public expense, which schools all the apprentices were compelled to attend. In order to encourage the pupils in the prosecution of their studies, which were carried on for the most part after working hours, it was determined to establish a central school in which a superior course of study should be given to such apprentices as might be selected by a special examiner, Professor (now Canon) Moseley; the number selected being limited to eight apprentices from the whole of the dockyards per year.

Those who were selected were to be boarded and taught at the public expense, in Portsmouth-yard, for three years, occupying the same building as had been used for the former school. The pupils selected were to have served at least four years of their apprenticeship, and were to have made satisfactory progress in the knowledge of the practical details of their profession. The subjects of the trial examination were to include three books of Euclid, and algebra to quadratic equations. The Admiralty undertook, that if the selected pupils passed satisfactorily through the practical and scientific studies at Portsmouth, they should receive appointments as officers in the dockyards, and that one-half of the vacancies for officers should be reserved for them.

In May, 1841, the school was opened, the Rev. Joseph Woolley, being appointed Principal, Mr. Herbert, Director of Professional Studies, under the superintendence of Mr. Fincham, Master Shipwright, and Mr. Hay, Teacher of Chemistry.

The number of students appointed in the first year was eight, in the second year nine. In 1850, none were appointed. In 1851, four left the school, their time having expired, but they received no appointments. Four new ones took their places. The remainder of those first appointed, and whose course had been completed, were granted another year of study as a reward for their success, and in order to enable them to acquire experience in designing ships. In 1852 these four, with the nine admitted in 1849, left the school, but appointment to office was refused to all but one. They were sent to the dockyards as supernumerary draftsmen. As the whole of these students had recommendations for appointment from the Principal and from the Master Shipwright, there was nothing to justify this breach of contract upon the part of the Government.

No other students were sent, and from 1852 till 1853 there were but four in the school. In September, 1853, the school was abolished by Admiralty order, Sir James Graham being First Lord of the Admiralty, as he had been at the abolition of the former school. The position of the members of this school in the dockyards was for some years a very painful one, owing to the neglect of the Admiralty, and the jealousy of the workmen and inferior officers. They are now slowly working their way into important offices, as they are able to display superior ability in the open competition between them and the other inferior officers of the dockyard. Three of them have been on the construction staff of the Admiralty more than eight years.

Thus the fortunes of naval architecture and the light of professional science were revived, but only for a moment, and, as a gleam, the feeble flame flickered for a moment, and then died out for the want of a little oil. Yet this lucid interval has in its turn repaid the country; for when the Admiralty are driven to a new reconstruction of the English fleet, and when they can no longer proceed in the routine of copying old plans and replacing old ships, they cast about to find in the rising generation of architects, men of fresh energies, and warm zeal, and modern science, and they find in their own establishment no rising race fit to take the places now rapidly becoming vacant by the retirement of the senior school, other than the half a dozen young men who were produced during that lucid interval by the utterly-despised and speedily-extinguished School of Mathematics and Naval Construction. As if to prove that little science was alive in this country, except that which a few months had grown in that ephemeral school, it is remarkable that our own *Transactions* show very few Papers of value on professional subjects that have come out of the dockyards, except from the pupils of this school. And it is not a little remarkable that our esteemed Vice-President, who was principal of that school, was the first to unite with me in founding this Institution. That the pupils

of that school were amongst its earliest promoters, and that another of its pupils became Secretary to our Institution, and Constructor of Ships to the Admiralty.

I have now brought this short and imperfect sketch down to the present time, and the question I have now to ask this Institution is,—here are we—men, let me call ourselves, of the Old School—advanced in life and rapidly retiring from its active labours. Here are half a dozen young men our only successors. Where is the young race of naval architects? Who is providing for them an education—such a fitting education as will enable them to compete successfully with, and to excel and go beyond, the accomplished, educated race of naval architects rising up in other countries? Is there any means existing in our profession by which a young man desirous of a career, and with adequate ability and industry, may obtain equal advantages to those possessed by the youth of other countries? I have to answer, there is not. I have, not long ago, had to encounter, in the education of my own son all the obstacles which a father wishing to train a son in all the discipline which his father had gone through, and to give his son all the advantages which every father must regret not to have enjoyed more fully in his youth. I have found too certainly, that there is no education in England for a naval architect; and if you ask me where an adequate education is to be found, what is my unwilling answer?—Across the Channel, in France.

It is in France, then, that naval architects are educated: the Polytechnic School of France, where naval architects receive their primary education, is crowded by pupils, by young naval architects, and naval officers and engineers from all parts of the world; and those nations who wish to ask a favour of the Emperor, ask as a favour that their most promising and best-educated youths may be received there. France is jealous of this education of her best youths, as of her choicest jewel: she does not willingly or often grant that privilege, and when she does it is only to a limited degree; but it is a privilege for which the most distinguished youths of foreign countries are candidates. And what is the highest ambition to which these educated youths—the flower of France—aspire? It is to be admitted by competition into the School of Naval Architecture. To this they are admitted at ages of from nineteen to twenty-three, after having proved themselves in a career of education and competitive examination to be the twenty *élite* of all France. They pass into the School of Naval Architecture on full pay, they remain there for three years students of the school—students in winter only, for all summer they are workmen—workmen in the dockyards practising their craft. In the first winter they learn the principles of naval architecture; in the first summer they see them put into practice. In the second winter they frame all the calculations of a ship, form tables of her weights, quantities, and equipment, and then construct a design of her out of their own head; in the second

summer they follow a design, not their own, but the nearest to it in size and nature through all its phases, laying down, taking off, and building in the yard. During the third winter they completely design and detail a marine engine of their own invention; and in the third summer they follow its details of construction all through some manufacturing establishment. But, as I have already said, so great is the competition to possess the services of these choice men, that before the third term is out, few of them are permitted to remain in the school long enough to complete their course.

It will be easy to conceive, after this statement, the astonishing progress which France has made both in her Royal Navy and in her mercantile marine during the last twenty years. She estimates the value of naval architecture sufficiently high to select as naval architects only those men who are the *élite* of all the local colleges and schools of France, and who prove themselves to be so after selection by competitive examination. These are the men who at the ages of from nineteen to twenty-three form the pupils of the Polytechnic School; and then comes the last selection from among those who have formed the *élite* of that school, and who have distinguished themselves by another examination of those who have a strong predisposition to the naval service, and who are promoted to pupils of the College of Naval Architects. The pupils of this college are therefore the "*crème de la crème*" of French talent; their passage through the School of Naval Architecture is the phase of transition from theory to practice—one half of the year is all theory, and the other is all practice—and after three years all further theoretical instruction ceases, except what they may continue to give themselves. Their whole minds and time are now given to practice: they become dockyard assistants, they are sent in succession to a variety of departments, and promoted through a variety of dockyards, so as to gain a knowledge of each. They are sent afloat to record the behaviour, and report upon the qualities of ships they have built; and wherever skill, probity, high knowledge, and character are required, they are employed. They are a body of men who can be, and are, implicitly trusted.

Such is the kindly and proud solicitude with which the youth and talent of the rising generation in France is tended and fostered. After such a statement, the other statement I ventured to make will no longer excite surprise. I said that these trained men were so much in demand, that they were scarcely permitted to complete their studies, before being drafted off to fill responsible situations in the dockyards, and I added, that everywhere they were coveted as the heads and conductors of large and prosperous establishments for naval architecture and engineering; and I may cite an example, which will conclusively prove the practical influence which the training of this set of men exerts both on the commercial enterprise of France, and adversely on the commercial enterprise of England. We know that there has grown up in the

Mediterranean, a powerful and successful rival, which has succeeded in displacing our own Peninsular and Oriental Company from nearly the whole of the coasting trade of the Mediterranean. It has been taken by a company who build their own machinery and iron steamboats in France. This company's ships are fast and well built, their machinery good and durable, and their career highly prosperous. The practical heads of their business are past pupils of the Polytechnic, and of the School of Naval Architecture. In like manner our West Indian Mail Companies have formidable rivals on the Brazilian line, on which for a long time they possessed a monopoly of the mail intercourse between Europe and Brazil. Their successful rivals compete with them in carrying the mails of Europe by means of ships and engines constructed mainly under the superintendence of naval architects and marine engineers, past pupils of the Polytechnic School, and of the College of Naval Architecture; and I may conclude by calling attention to the fact, that under the same skilled superintendence, there has been created a new fleet of French iron steam-ships in which there has now been commenced with surprising success, and perfect regularity, a rival line to the imperfect and unsatisfactory service of the Peninsular and Oriental Company. And thus by sheer force of talent and skill appreciated and fostered, France is snatching from us some of the valuable trades which we had fancied were exclusively our own.

I have confined myself mainly to France, as the most striking example of the successful policy, by which the rivals of England have contrived to snatch a large share of those gains, and of that reputation, which should have been maintained by us as a most valuable possession. We ought never to have allowed any part of our maritime superiority to have slipped from us, either naval or mercantile. It has been my fortune during the last twenty years, to watch the progress made by rival manufactures to ours on the Continent, and I have been sorry to perceive how we have permitted a rapid, and successful competition to grow up unmet. We thought we were in possession of natural advantages, which could secure to us at least a monopoly of the iron manufacture, the engine-building, the iron ship-building, the railway making, the locomotive engine-building, and the general manufactory of heavy machinery for the Continent of Europe, and we thought we had nothing to do but to jog on and prosper.

We had apparent good reason for this. We had iron abundant, easily got at, and cheaper than that of any other nation. We had coal better, cheaper, and inexhaustible. We had a population of skilled workmen outnumbering that of all other nations—men who were industrious, skilled, and justly proud of their work. We had also the start of all other nations, and cheaper capital to work our plant than any other country.

Foreign nations saw that in all these points we could beat them, and were nearly hopelessly in advance; but there was one point which seemed to them our weak point,

and they determined to make that their strong point. They saw that we despised science, and called it mere theory: they saw that we neglected technical education, and boasted of our ability to do everything by rule of thumb, and on this weak point they resolved to attack us, and combined their plans with a forethought and skill that have been justified by wonderful success. Everywhere they reared schools of mining, and schools of mechanics, and colleges of engineering, and taught the young men of Germany, France, and Austria to be better draughtsmen, better calculators, more skilful chemists, better mathematicians, better instructed in the laws, and properties, and mechanical qualities of matter, than the great majority of workmen and foremen in England. They extended this upwards to give a high technical education to their engineers and architects, and by this means they believed they could at last effectually compensate by education and science for their own want of cheap materials, and of rule of thumb routine. The result is, what I have already shewn in France, and what I may extend to Germany, by saying that whereas we had originally the making of all the lines of railway, the construction of all the iron ships, the manufacture of all the iron rails, locomotive engines, and most of the machinery and plant for Germany, they not only now make their own iron and steel manufacture, and locomotive engines, but intrude backwards upon us a formidable rivalry in our own markets as successful competitors.

I hope I have satisfied you all how wisely, and with how much forethought France and Germany acted in using this instrument of superior education against us, and it is no wonder perhaps that we neglected it, because it requires at least one generation for such education to tell, and all I adduce it for is to found on it this one question, and I put it to you with serious earnestness—Do you think that we are justified in seeing the generation that is to follow us, grow up into matured professional life without giving them at least as good an education as their competitors in the race of life are receiving in other countries? Whatever difficulties we in our youth may have conquered, and removed out of our way, can it be wise in us to leave our successors exposed to the same difficulties and defects which may have retarded our progress? And even if we be satisfied with the measure of our own past education, let me venture to suggest that the progress of science, of discovery, and of improvement, is going on at such a pace throughout the whole civilized world, that I do not think the very best education we can conceive, or at present contrive, will be more than sufficient to enable our successors to compete on fair terms with their ambitious, jealous, and accomplished rivals. It seems to me an unquestionable obligation to the new generation to give them a start that shall be in no way inferior to the rising race of engineers and architects in any country of Europe.

It appears to me the special concern of this Institution, comprised as it is of the most

eminent architects, shipbuilders, and naval authorities, both of the royal and of private establishments, to charge themselves with the duty of foresight and forethought, and proper provision for the education of young men who are to fill our places, so that they shall do credit to the nation, and maintain the honour of the craft. We have capital dockyards, both public and private, in which they can acquire the manual dexterity and practical experience of shipbuilding; these are points in which we have never been deficient, and perhaps still are superior to the majority of foreign nations. Let us make sure, therefore, that we are also their superiors in the science and skill of a higher order which are necessary in order to direct the experience and craft of every class of workmen, and then with the capital and the resources of England at their command, our successors will find no cause to reproach us with the neglect of their interests.

I say this education is our special business as an Institution, because the Admiralty, the special department of Government to which it belongs, having twice undertaken it under the pressure of the country, have a second time thrown it down; and any future Government may safely excuse its continued neglect, if the Institution of Naval Architects has failed to make representations or efforts for the advancement of that science, and that education, of which they are the personal representatives. It is therefore that I beg of you now to undertake the task of founding the English College of Naval Architecture, and I undertake that if you do so, you will find it perfectly practicable to carry it through, not without difficulty, but with complete success. There are among ourselves in this room a sufficient number of able men, to set going such an undertaking. The Council possesses all the skill to manage its organization, and direct its affairs. The power and weight of the Institution, augmented by its rapid success, and established usefulness, would give it a weight with the Government, and with the public, which it would be very difficult even for an adverse Admiralty to resist. Even if it did, we should not find it impossible to compel that department, through the weight of other branches of Government, to avail themselves of the resources, by which the public service might for the future be able to depend upon receiving a continued supply of well-trained, and well-educated, skilful, scientific, and practical men, to fill every department of charge and responsibility in the dockyards, and in the technical service of the Admiralty.

In such an Institution, the naval architects and shipbuilders of the private dockyards, would share equally in the advantages of high professional education; and, let me add, that I do not think it would be found to be without advantage, that naval officers and engineers afloat should join in the completion of their studies in such an establishment; for let me assure the members of the naval service present, that I know it to be the opinion of naval officers, whose opinions are entitled to the highest weight—officers of other naval services as well as our own—that the next naval war will require of these

officers, in addition to the highest skill in navigation, seamanship, and gunnery, a knowledge of the scientific properties of their ship, an acquaintance with the structure of the marine engine, a familiarity with the machinery which must steer their ships, as well as propel them, and with the mechanism which must work and direct their huge artillery, that will task the skill and science of officers infinitely more than their past service has ever done; and this I impress on them the more now, because we stand at a transition point, where tradition, and routine, and experience of the past, have become obsolete, and inapplicable, and the man of the future is the man who has been acquiring unbounded knowledge, resources, and skill, and who is ready to bring them all to bear upon unforeseen circumstances, and unprecedented combinations.

All these wants then of every branch of the profession our new Naval College may advantageously fulfil. What sort of course that education ought to be in detail, I must leave to the Council to consider and mature.

Among the various points which will have to be settled by the discretion of the Council, will be the relation which ought to subsist between the Council and the Government in the establishment of a Naval College. That the Council should determine the nature, course and term of study—that it should select the professors and assist at the examinations with which the course might terminate, seems natural: it seems as natural that the Government should provide a building and defray the expense of the maintenance of the establishment. The Government would have a right to send up from the dockyards every year, a certain fixed number of shipbuilders and engineers who had acquired a certain amount of mathematical and mechanical knowledge, to receive the instruction necessary to qualify them for the rank of draughtsmen, inspectors, foremen and assistants. These students would receive during the term of residence, their full pay, an additional sum for board, and the Government would pay for them the usual student's fee for the term. Students, not members of the dockyard establishments, would be admitted to the course on the payment of a higher fee. Naval officers as students might be admitted on equal terms with the latter, or the college fees might also be paid for them by the Government. The salaries of the professors would be apportioned by the Council of the College, with reference to the nature of their duties and the occupation of their time.

In regard to the course of instruction to be given at the College of Naval Architecture, it would neither be practicable nor desirable exactly to copy the method pursued in the French, or any other college. Naval Architecture manifestly comprehends three great branches—

1. Naval design, or calculation:

2. Practical construction, or executive shipbuilding; and

3. Steam navigation, including engines, boilers, and propellers.

In these three departments there would be found ample employment for the study of three winters, and for the employment of the whole time of the pupils, and as it might be feared that all of them might not come to the college as perfect mathematicians or as good draughtsmen as might be desired, it would probably be expedient to attach courses of the higher mathematics for such students as might require that aid.

It is quite plain that such a college as I have roughly sketched would neither interfere with, compete with, nor displace any existing Institution or system of education: on the contrary, it would be a fitting supplement to any education, however thorough or profound, which the student had possessed before. Even a profound mathematician from Cambridge would find in the calculation of a ship's qualities and behaviour on the surface of a wave-troubled sea, problems to exhaust all his resources in the use of the differential and integral calculus: a good chemist would find tough enough problems in the preservation of iron ships from fouling, and the prevention of iron hulls from oxidation, and in the questions of the screw propeller, and of marine artillery; and the accomplished theoretical mechanician would find a boundless field for his ingenuity. Instead of having to fear that this College would do what others would more easily overtake, there is much more reason to apprehend that existing Institutions of education would fail in sending to us pupils sufficiently well furnished with the preliminary instruction necessary to solve the difficulties of naval design, calculation, and construction.

We should ask the Government to allow these young men to come to London without forfeiting their pay, and to allow them board wages during their attendance at the College of Naval Architecture. I believe that the number who would above all things desire to avail themselves of such an advantage would be much greater than the dockyards could afford to spare. I say, therefore, that such a set of prepared pupils would be enabled to join this Naval College with advantage, and Dr. Woolley will bear me out that we have in our dockyards preliminary schools in which a certain quantity of mathematics and mechanics are taught, and a certain preparation given, which would fit them to enter. If that were done, we should no longer be obliged to send our sons, as Mr. Laird and I have done, to France to be educated as naval architects; and we should be able to offer a course of education to all the young professional shipbuilders, naval architects, and engineers, who are rising up to fill our places. And let me tell you that the coming generation wants a deal more knowledge, a deal more education, a great deal more professional cultivation, and a great many more advantages than you and I have enjoyed, in order to keep their place with other people in the country. We should be able to form a large and practical school of naval

architecture in this country; and I think this is a fitting task for the Institution of Naval Architects to undertake. I do not think it would be considered an interference with the functions of the Government. I do not think it ought to be considered an interference with the functions of the Admiralty, for they have already twice refused those functions and thrown them down. It therefore seems to me to be our imperative duty to undertake the education of our own profession. In regard to difficulties—there are difficulties in the way I know; but if half a dozen of the honest, earnest men whom we can count upon in the Council are supported by the great body of the members—the shipbuilders and professional men who form the members of this Institution—I believe we should carry that into effect, for which we should receive the gratitude of the next generation of naval architects.

With the hope that you will agree that this should be recommended to the Council as a subject for their careful inquiry, as a subject for their careful study, and as a subject which ought to occupy their serious attention, and, if possible, employ the labours of the executive;—with this hope, I leave it in your hands, making one observation as a postscript. It is, that I am strongly of opinion that the time has come when naval architects ought to have a good inkling of naval architecture, and a good inkling of engineering; and I think that if they do not soon take to it, they will very soon find the want of it. I do not see why the Members of this Institution should not also encourage this somewhat larger view, that some arrangement might also be made, by which the members of the naval profession, who are really one with naval architects, if they were not continually being separated too much into departments having something like antagonism, might be embraced in this College; because, I think that which is a good education for us, is, up to a certain point, a good education for them.

DISCUSSION.

Mr. H. Chatfield, Vice-President, I.N.A.: I feel much obliged to Mr. Scott Russell for his very able and candid Paper, and I rise as an old member of the School of Naval Architecture to offer a few observations upon it. Some of the remarks have a very personal relation to myself and others like me. As soon as the School of Naval Architecture began to work, one of the first things that the late Sir James Graham did—he being First Lord of the Admiralty at the time—was to put us aside, and appoint Sir W. Symonds as Surveyor of the Navy. That was a terrible drawback. On the retirement of Sir W. Symonds, Sir Baldwin Walker was brought forward, who upon his appointment said, "I am not a "shipbuilder. I can't construct a ship. What is the use of making me Surveyor of the Navy?" Of course, he selected a most able man, and one who understood the subject, to assist him, and through his instrumentality the work was performed. I speak not from guess-work, but from what I know to have

been the case. I heard a trial at Westminster Hall the other day, at which the first adviser of Sir Baldwin Walker was present, and I found that his answers were such that he spoke for himself and Sir Baldwin Walker. He had all the responsibilities of the office but none of the honour, and that was the way in which the members of the School of Naval Architecture were put aside. We have now made a change and shall see how it will work. I feel satisfied from what Mr. Scott Russell has said that the plan which he proposes is exactly similar to the plan on which the School of Naval Architecture was formed—calling persons here and there to help them. The dockyard people should, I think, take the lead. If you educate men to understand their work they are the men to do it. Mr. Scott Russell has stated, that in France, those who are intended for the profession of naval architects are kept at the schools in Paris for a period of three years, and from there they are sent to the dockyards. Now take the case of a man studying a business. I will ask what three years will do for him? You may teach him the elements of the business, but he cannot learn the business in three years. It is the man who has given up his lifetime to it—that is the man who should be pursuing the subject. I say, that unless encouragement be given to men who can work the subject out in all its bearings, we never can expect the success we pride ourselves upon.

I was certainly a little astonished to hear Mr. Scott Russell speak in the way which he has done of the superiority of the French naval architects. When they constructed their first iron ships they required a good deal of doctoring at our Admiralty. I am willing to give them credit for what they do, but I cannot give them credit for their designs. The French students are sent to our dockyards continually, and when they come over here they talk to practical men, and go back with the idea that they know a good deal about shipbuilding; but they get the knowledge which they use from us. With regard to their designs, they have sent several over which have given a great deal of trouble. The Russians built some ships a little while ago which were obliged to be finished off by our Admiralty. The fact is, that like all other education, unless you proceed upon fundamental principles you will never produce successful naval architects. We may have glowing accounts of what they are doing abroad, but instead of our imitating France, I think France would do better to imitate us. We know more of the subject than the people who come here do. We have the power in our own hands, and as soon as we give up that power we shall become second to France, and not till then.

I cannot say that I agree with many things Mr. Scott Russell has said, but I am governed by my own feelings. I was one of those appointed by the Earl of Haddington, with Mr. Creuze, and Mr. Samuel Read to make a report, and that report occupied us two years and a quarter. We went most fully into the subject committed to us, but I deny that men not brought up to the profession, and not thoroughly grounded in it, could have drawn up that report. A man may be a clear mathematician, and skilful in drawing up reports, but he could not make a report upon the whole subject as was done in the case referred to. I have left the Service for some years, but I have, nevertheless, a strong desire to see the science of naval architecture advance; and the only way to do it, in my opinion, is to give good practical education on the subject.

Mr. Samuda, Mem. Council, I.N.A.: It appears to me that the matter we have to take in hand here, is the way in which we, as a body of practical naval architects, can work out the results which we all desire. The admirable observations of Mr. Scott Russell must be extremely agreeable to all of us. We must all feel that wherever education can be made useful to advance those persons who are to follow us in our profession, it would be a great pleasure to all of us to assist in getting it developed. But I

confess that, when Mr. Scott Russell puts before us a scheme for raising a college exclusively for the benefit of naval architects, or for the education of naval architects and engineers separately from the other great colleges which this country possesses, I believe we should miss the very object we have in view. I believe that a man's chance of success in life is obtained by two things—by having the soundest and best general education which his father can give him; and by obtaining a specific education in the branch of business that he is going to carry out. I believe that my son will return to me from Eton, as well fitted to be a naval architect by the practical education he will afterwards receive, as if he were educated in a school of naval architecture.

Mr. Scott Russell: You mistake me in supposing that I ever meant to put a boy, as a preliminary step, into a school of naval architecture, or to have a separate college for that purpose. When they have finished their general education, the man—not the boy—requires the technical part of his education.

Mr. Samuda (continuing): What I meant to convey was this—I do not feel the same necessity for sending my son to France to receive his education which Mr. Scott Russell has felt, and I know that he must have felt it deeply from having sent his own son there. I believe that the groundwork of the education which my son will receive at the college here (Eton) will be sufficient to enable him to possess all that amount of ability—and this applies I think to all boys—which will be sufficient to give the means, when he comes into the shipbuilding yard, and is placed under scientific and practical men who have had the same preliminary education as he has had, to develope him as a shipbuilder. And I believe that if, instead of putting him into the shipbuilding yard, I were to put him into such a college as Mr. Scott Russell describes—in which during each of the three years allotted a separate branch of education was imparted—I believe I should be doing what I think is the great error of all education. I believe that the success of English results, as compared with foreign results, consists mainly in this, *viz.*, that in the French mode of education you obtain a large amount of superficial education, instead of what a man must have if he wishes to rise in his profession through practice upon the groundwork which he has obtained in the college. I do not think we shall succeed in raising up successors to follow us if we seek to establish a separate school for the purpose. It appears to me, that if we were to seek to develope particular classes in all these colleges, we should assist in getting rid of the opportunities which the boys possess in the yards when they come from college. Thus, I consider that the education at Cheltenham is of a better engineering and scientific character than is gained at the older establishments of Eton and Rugby; but I believe that such superficial knowledge as is got in the foreign establishments is not the thing which would give that amount of practical advancement, which is the personal qualification that all English engineers, shipbuilders, and mechanics appear to possess.

Rear-Admiral Sir E. Belcher, C.B., Assoc. Mem. Council, I.N.A.: It may be asked why I stand here amongst a body of naval architects to offer any observations on such a subject as the present—I, a man without a scientific education but what I have gained by my own application, for I was too young when I left school to enter a college, previous to my going into Her Majesty's Service.

In the course of my early life I possessed the intimacy of Sir Robert Seppings, Sir W. Symonds, and Admiral Hayes, and possessing the friendship and confidence of these three men I may be supposed to have gained some few of the sparks that were struck off from them.

From the year 1815 to 1824, I practised shipbuilding with my own hands, and in the woods of Bermuda, that I might not be seen as an officer working. I practised as a naval architect. The rudder

was a matter I very early turned my attention to. I offer these prefatory observations for my presumption in addressing you upon subjects of naval architecture.

I will first take to the question of high speed. Her Majesty's ships *Southampton*, *Winchester*, *President*, and *Warspite* attained a greater velocity under canvas than, I believe, ever was attained by vessels of their tonnage (about 1,800 tons) under steam. Those vessels were built by what were then termed the "*United Abilities*." The *President* was an American model, and was taken to pieces and rebuilt. The *Southampton* was over-pressed with canvas at first, and she, when relieved of one-third of her canvas, went over 17 knots an hour, and I don't think the French builders will beat that.

As to the capacity of our naval constructors, I have had a great deal to do for the Admiralty from the year 1830 up to the last time I held command. In the case of the *Erebus* and *Terror* I was entrusted by the Admiralty under *carte blanche* with the alteration and equipment of those vessels for the service in which they were originally intended to be employed.

I do not go to the length that some appear to do in admiration of the French ships; and I will make this observation—that in all my professional career, whenever a French ship has been lost or run upon rocks, she has in some instances failed from faulty construction, and in others, want of ability in getting her off.

We are much indebted to Mr. Scott Russell for his Paper. There are many valuable points about it, and many suggestions which will strike every observer who wishes to judge rightly.

I am very glad to find that the public has now been set right with regard to our Secretary, Mr. Reed. He has been described as a man unfitted for the post of Constructor of the Navy; but we have heard a complete refutation of that insinuation as regards the course of his education, for we find he has passed through the requisite courses to fit him for that appointment which he holds. We have heard the beautiful language in which he expresses himself. If he is wanting as a constructor, he is not wanting as an orator; and I am satisfied that Mr. Reed will become, as he progresses, a talented man in his profession.

As far as the construction of these French ships is concerned, I have often spoken of them before. I have been on board of them, and have seen their finish, but I am not satisfied with the workmanlike manner in which they are finished. A constructor may draw plans, and direct this or that to be carried out, but he cannot make the men who are to do and finish the work. In astronomical instruments and small affairs of that kind the French workmen excel; but, in ordinary wood and ironwork, they are eclipsed by the British workman.

As to the position the British naval architect should occupy, and where he should be taught, I think Greenwich would furnish a good position for a college, and, I would suggest, that in that college there should be classes for education in all the higher mechanical branches, and let the students who may elect to serve at sea in the lower capacities, be educated as the warrant carpenters of the Service, so as to be competent to perform any repairs demanded on board our ships of war. You would then have competent warrant officers, and not men made warrant officers merely for their good behaviour.

As to the education of naval architects, I am, as I have told you, a workman myself, and I believe I have a certain talent of invention, and the inventor will rapidly seize upon what passes before his eyes; therefore I say, if you wish to instruct your sons for constructors, send them into the British merchant shipyards, where they will see numerous applications in mechanics which they will not meet with in the naval yards of any other country.

As far as regards the expense that must be incurred by establishing these naval schools or classes at

Greenwich, I would say, follow a similar course to that in the Royal Artillery, at Woolwich: no expense is spared there, and every facility is granted to the students. All the chemicals, all the tools are granted free, and the students are enabled to follow the studies which they previously pursued at the Woolwich Academy. Yet how many amongst them do we find as genuine inventors? Very few. But if Her Majesty's Government would grant a similar amount of money to the Naval Service that is given to the Military—if they would give some assistance to an Institution like that in Scotland-yard, I am sure that very great advantage would accrue to the public service from the discussions that take place there; and seeing that they give such enormous sums to the Kensington Museum, they would in a similar manner bestow a few thousands upon the establishment of naval classes at Greenwich, it would undoubtedly prove a most important advantage to the country. At Greenwich, I think the classes should be established, because it is not only easy of access from town, but it would be in the vicinity of most of the great naval yards, as well as the dockyards of Deptford and Woolwich, and more information would be gained by the students in one year in such a locality, than they could acquire in a lifetime at Portsmouth.

Mr. J. Grantham, Mem. Council, I.N.A.: I have no wish to prolong this discussion, but I cannot forbear offering one or two remarks. In the first place I am not inclined to agree altogether either with Mr. Scott Russell or with Mr. Samuda. I differ from both my friends on some points, and I agree with them on others. The suggestions of Mr. Scott Russell are extremely valuable—they are suggestions which we ought most carefully to mature. I very lately advocated a similar proposal to this at Liverpool, when Mr., now Sir William, Brown contemplated the formation of a museum for the town. I suggested that a department should be set apart for models and contributions connected with naval architecture, for the special purposes which we have in view in this Institution. I cannot help feeling that London should be the great centre for all this, and upon that point I cordially agree with Mr. Scott Russell. I do not, however, quite follow him in the contrast that he has drawn between England and France as regards the education of naval architects. Regarding the few isolated points which Mr. Scott Russell has touched upon, no doubt he is correct; but when I see that the naval architect of England is not dependant upon the Government dockyards alone—when I see the splendid fleets of vessels which are turned out of the private shipyards of this country, and which originate with men who are not in the dockyard service at all, I feel that Mr. Scott Russell has omitted a most important feature connected with this country, in which neither France nor any other country can bear comparison. When we look at our merchant marine and see what is doing in that direction, we must feel that if that be ignored, a partial view has been taken of this subject. I believe there is an amount of talent and an amount of science to be found in our private shipbuilding yards which, if concentrated into a school, would be found of the highest order. And I reason in this way, not only from personal knowledge of a great number of these men, but from a knowledge also of what they have produced. They do not build fighting ships, but they do produce most magnificent specimens of naval architecture; and when we look back a few years, we see how far they were in advance of the Navy in the introduction and efficient working of steam. Where did this originate? Principally in the hands of educated men. But how were they educated, and what for? I appeal to the facts of the case. It originated with engineers—not from naval architects! at least only to a small extent. We engineers led the way in that matter. Mr. Scott Russell is himself an educated man of the highest order in the exact sciences. I appreciate highly this advantage as likely to lead to the greatest amount of ultimate success. The education I would recommend is, a good school education first—give the youth the A B C of his work; I then recommend that this education should be matured and followed up most

carefully after he leaves school; but as we all know boys soon get tired of mere science, and therefore as their minds are developed, we should combine the scientific education with the practical. The most effectual way to do this is to establish schools in the localities where practical works are in operation, and carry them on as nearly as possible together. I may mention a little incident in my own education. I was in an engineer's works, where the principal, though not a practical man, had obtained high honours as a mathematician, and he kindly asked the young men of the establishment to spend an hour or two with him in the middle of the day in the study of mathematics; and I confess I took great pleasure in the work, and I got on tolerably well with it. I should now find it difficult to work out a problem in Euclid, or a complicated cubic equation, but the results produced are left. This kind of education I think is best suited as a whole for the training of practical men; and I cannot help feeling that this Institution will not fulfil its mission without taking the subject into consideration, as laid before us by Mr. Scott Russell. And I may say I am delighted to see it springing from a private Institution, and not from the Government. We have been accustomed in all matters in this country to depend upon individual and private efforts, and the Government very wisely leaves them in such hands. I therefore feel that we may do a great deal, at the same time asking for such co-operation as the Government may think fit to give us. I recollect a session or two ago, it was considered by some that I was going a little too fast in a matter of this kind. I appeared in antagonism to a great establishment—Lloyd's Register Committee. I was supported in my views by many persons, but perhaps I was premature in what I wished. Seeing how much naval architecture was dependant upon the mercantile marine, and feeling that Lloyd's Committee exercised an immense influence upon the shipping of the country, I desired to give more efficiency to its regulations. Recollecting how much naval architecture in this country was crippled through imperfect legislation with regard to the old registry laws, and how they spoilt a large class of the mercantile marine of the country; how naval architecture was in fact altogether ignored—we cannot be too careful in removing every similar impediment. I feel that this Institution has this great mission, and I feel also that limiting the work of this Institution to a few meetings at one period of the year, is curtailing it of many of the great advantages it might produce. I would ask the Council to take this subject into their serious consideration.

The Rev. Joseph Woolley, LL.D., Vice-President, I.N.A.: Little is left to be added to that which has already followed the reading of Mr. Scott Russell's Paper. There is one deduction, however, I draw from what that gentleman has said. It is that education in the public service, as naval architects, is non-existent. Whether it is a sound state of things that those persons upon whom our great establishments are to depend should be left without the advantages of sound professional education, I think cannot be questioned. Mr. Scott Russell has shewn us that the Admiralty have twice endeavoured to remedy that state of things, and notwithstanding that their endeavours have met with a certain amount of success, they have on each occasion withdrawn from the undertaking. It is, no doubt, as Mr. Grantham has pointed out, the genius of this country, that we should depend more upon private and individual operation than upon the Government. Therefore, I think that is an additional argument why we should not look to the Government itself to establish a school for the education of our naval architects; but why we, representing as we profess to do the naval architecture of the country, should establish an institution to carry out that which the Admiralty have shewn they are either unwilling or unable to carry out for themselves. We may do so, I think, without attributing blame to the Admiralty for the action they have taken. It was considered that their demand for skilled officers was small, and that the expense of

maintaining such an establishment was more than was justified by the requirements of the Service. Mr. Samuda and Mr. Grantham have alluded to the fact that a great deal of the eminence of naval architects in England is owing to the private, and not to the public shipbuilding establishments, and they have challenged Mr. Scott Russell upon that point; but that gentleman mentioned a fact which we ought to bear in mind in relation to this subject. He told us that those gentlemen educated in the School of Naval Architecture in France are not only drafted off into the public service, but are engaged in the private establishments. And he, moreover, mentioned the important fact that one establishment in France has succeeded in driving out the Peninsula and Oriental Company from the Mediterranean, and that that establishment was mainly supplied by the trained men from the School of Naval Architecture. That is a fact which speaks volumes, and that, combined with many other points mentioned by Mr. Scott Russell, ought to make us hesitate long before we reject the scheme which he has proposed to us.

Mr. E. J. Reed, Mem. Council, I.N.A.: Without occupying your attention many moments, I may be permitted to offer one or two observations on this subject. In the first place, it has been announced by Mr. Scott Russell, and assented to by those present, that there exists no adequate means of education for naval architects in Her Majesty's Service at this moment. If that is true—and I believe it to be so—then that is a point from which we can start. Mr. Samuda and Mr. Grantham both appear to think that the means existing in the private service for education in shipbuilding are sufficient.

Mr. Samuda: Allow me, to say that I drew no distinction between private schools and Government schools. I only expressed my idea that if the education was of such a description as it would have to be if an establishment were provided solely for naval architects, it would fail of producing those complete, perfect, and practical men whom we have got at the present day, and I went on to say that I believed education could not be too exclusively followed in early youth, and that then nothing more was required than to transfer the boy from the college to the practical establishment where he would be educated in the specialities of his art, which he could never learn in any college; but that he could arrive at perfection in that art only by continuous practice. I did not draw a distinction between that which he would learn in a private or public shipyard. But I do agree with one point in Mr. Grantham's observations, which is that the complete education of a naval architect is only to be obtained by their being educated in both the theory and practice of engineering.

Mr. E. J. Reed (continuing): To this little interruption I am sure no one will object; but with reference to the capabilities of engineers, who are without special culture as naval architects, for dealing with this question practically, I will advert to one fact. A month or two ago, I attended a meeting of a neighbouring Institution at which an engineer read a Paper upon the rolling motion of ships, and the fundamental assumption in that Paper—an assumption which not a single person rose to contradict—was that in all ships that go to sea the centre of gravity must of necessity be below the centre of buoyancy to make them safe. That doctrine was received without question by the meeting; and even after I ventured to point out the grave inaccuracy upon which the whole Paper hung, and showed that the centre of gravity of sea-going ships was far above the centre of buoyancy, and after the author of the Paper admitted he was wrong, the Chairman of the meeting said he had no doubt the chief conclusions of the author were correct, notwithstanding the fundamental error with which he had started. This is a specimen of the sort of things that pass for discussions upon naval architecture among men who have not been taught the specialities of the science. The great misfortune is, that no man who has not been thoroughly trained

to the profession of a naval architect ever did, or ever will, believe that a thorough training is necessary; but after having had myself to work very hard under the tuition of Dr. Woolley, and having worked very hard for many years since, I still feel that I have a great deal yet to learn; and I cannot agree for a moment with those who represent that there is no need of deep and profound study in the principles of the science on the part of the naval architect. I may also state, with reference to the notion that private shipbuilders cultivate the study of the profession more than those in the Government Service, that whether professional knowledge abounds or not in our private shipbuilding establishments, they have over and over again had drafted into them gentlemen from the Royal Dockyards; and most of the higher offices in the private service have been, and still are, held by gentlemen trained in the Government Service. If it is true that the state of education in the Royal Navy is deplorable; if it is true that it is also deplorable in the private service—as I believe it is—then the necessity for some action exists; and the question arises whether we are to seek to carry our object into effect by finding fault with the Admiralty for establishing and abolishing several schools in succession, or whether it would not be a more manly, prudent, and wise thing to set to work among ourselves to remedy this state of things. I believe it would be a very wise thing—a thing which no Government likely to hold office in this country for years to come would dream of opposing—for this Institution to try in some moderate and wise way to provide the necessary education. You will probably find some antagonism between the Royal and the private services—a good deal of jealousy—but if we could all meet here and devise a simple means by which young men may obtain that amount of professional knowledge which is indispensable to the mastery of naval architecture, we should do good—should remove the existing line of demarcation, and not only give the Government an opportunity of introducing men from the outside, but also give private men an opportunity of taking better officers than ever from the Government establishments. I would say, in the peculiar position in which I happen to be placed, that I would not engage in any great scheme on this matter which would be likely to break down; but if such men as Mr. Scott Russell, Dr. Woolley, Mr. Chatfield, Mr. Samuda, and Mr. Grantham would meet together, and consider some practical means by which the requisite education could be provided in connection with this Institution, I have no doubt it could be done. And I think with Sir Edward Belcher that Greenwich would perhaps be a good place for the school, because in any system of education of naval architects you must combine theory with practice, and enable your students to see what is going on in the Royal and private yards. That is a necessity which no one can doubt, for as Canon Moseley said yesterday, "When there is an antagonism between theory and practice, theory must be in the wrong." But I feel it is some discredit to us as naval architects to know that we are behind-hand with many questions of importance—that we are obliged, for example, to commit the question of the rolling of ships to my friend Mr. Froude—an engineer—and that he, an engineer, and not professionally a naval architect, has taken a high position in respect of one of the profoundest problems in naval architecture. At the same time I feel proud that such men as Mr. Scott Russell and Mr. Crossland are able to meet him on that profound and difficult problem. I think if the Council go wisely to work, avoiding everything like reflection either upon the Admiralty, or upon private shipbuilders, and take it up on the ground that naval architecture is a profession in which profound study is indispensable, and in which practical experience is equally indispensable, they will succeed in providing that education which we all feel the want of at the present time.

The PRESIDENT (the Right Hon. Sir J. S. Pakington): I am quite sure no one present will regret the time that has been occupied by the discussion which has just taken place. I have listened to it myself

with great attention and interest; and I am rejoiced at the tone and spirit with which the subject has been treated by a succession of gentlemen, all of whom are more competent than I am to express an opinion upon it. But I cannot permit this discussion to close without stating how cordially I concur in that feeling which, as far as I can collect, is a perfectly unanimous feeling, *viz.*, a feeling of gratitude to Mr. Scott Russell, for the admirable address he has delivered to us to-day. It appeared to me to be a most striking address: it appeared to me to be a most apposite address, and one which I cannot help saying openly may lead to beneficial practical results. It appeared to me that that address was full of enlightened views, carefully and admirably expressed; and, further, it appeared to me to be painfully full of considerations, many of which are of a very humiliating character, and which are entitled to the gravest consideration of the whole public, but more especially of a scientific body, such as I have now the honour to address.

Mr. Scott Russell, in the course of that address, touched upon a subject with which it has been my fortune to deal. He referred not only to the education of naval architects, but in a few sentences referred to the great question of education generally, and upon both subjects he spoke not only in a positive sense but in a comparative sense. I am sorry to say many have been the occasions on which, in speaking myself on the same subject, I have been compelled, with a due regard to what I believe to be the truth, to indulge in the same comparative language; and, whenever I have done so, always to the disadvantage of my own country. Not more than three or four months have elapsed since, in addressing the Philosophical Institution of Edinburgh on this very subject, I devoted a very considerable portion of my address to pointing out in terms of deep regret, that even as regards Scotland, which is far ahead, I am sorry to say, of this country in general education—even as regards Scotland, it was matter of deep regret and serious consideration for the inhabitants of this country to reflect upon the manner in which almost all the civilized nations of the world are now going ahead of us on this subject. Is this, or is this not also the case with respect to the important subject more immediately connected with our Institution—the subject of naval architecture? I am more disposed myself to view this subject as a positive rather than as a comparative question; but I am disposed to believe that Mr. Scott Russell is right; and that viewing it as a comparative question, that England is not in the position in which England, above all countries of the world, ought to be. Mr. Grantham has referred to the fact—the fact which no one can deny—of the great eminence and the great success of several of the private shipbuilding yards of Great Britain. No one is more disposed than I am to do justice to those establishments. Not many days have elapsed since, in my place in Parliament, I found it my duty to state the high opinion I entertained of the ability and high accomplishments of those gentlemen as a body. I entertain for them the highest respect: and I am disposed to think that a general concurrence in the comparative views of Mr. Scott Russell is consistent in that respect; and we have before us, in confirmation of that view, two facts. We have had our attention called to the striking statement made by Mr. Russell, with regard to what is at this moment being done by the French establishments in the race of competition with English establishments. We have before us another striking fact which, I think, Mr. Samuda, high authority as he is, has failed to meet. We know when you refer to the private shipbuilding establishments of England, as in all other professions, there is a certain list of eminent names which suggest themselves to the mind. Amongst that list, no one will deny, you find the names of Mr. Scott Russell and Mr. Laird. We have to-day the statement brought before us that, so far at least as those two eminent names are concerned—names and authorities on this subject which no one can question,—that those two gentlemen, rightly or wrongly, have thought it due to the interests of their children, that if they are to be hereafter eminent in their own profession, it is desirable that those children

should study their profession in France. This may be prudent on their parts: it may be necessary or unnecessary, but it is a fact which we cannot dismiss from our own minds. And I would further say on this subject, that, whilst giving due deference to Mr. Samuda's views, and acknowledging the weight of his authority as one of those eminent names to which I have referred,—I am an old Etonian myself—and I would say that if I wanted a son of mine to be an eminent shipbuilder, the last place I should send him to would be Eton College. I may be right or wrong, but that is the view I take of the practical part of this question.

No one can wonder that upon a subject of this kind, and in a meeting like this there should be some difference of opinion, but I think there will be no difference of opinion upon the fact that the suggestions of Mr. Scott Russell are of a character well deserving of reflection, and coming once more to the view of this matter as a positive rather than a comparative question. I have been—not only since the words of Mr. Scott Russell fell upon my ear, but long before—under the impression, looking at this subject in a positive point of view, that England is and has long been positively deficient in those means of instruction and education for the great profession of naval architects, which she, above all countries, ought most carefully to cherish and aid. Therefore, while Mr. Scott Russell, highly as we appreciate the ability with which he has addressed the meeting, will not expect us to commit ourselves to details and precise modes of proceeding, I trust it will be the unanimous opinion of the meeting that the suggestion of Mr. Scott Russell is one which ought not to be allowed to be laid aside; but we ought to make it our duty carefully to follow it up and consider it. I believe it may be productive of most beneficial results, and I hope that the Council of this Institution will follow it out. I own I was struck by the suggestion of Sir Edward Belcher that it might be well, rather than having a college in London, to let this Institution exist at Greenwich; but I do hope, as a practical result of what has taken place to-day, that we shall determine in our minds not to let this matter drop, but that it shall be the duty of the Council to devise the best means of giving practical effect to the views that have been laid before us; and for myself I would say, that nothing would give me more pleasure than co-operating with the Council for this purpose in any manner which may be in their power.

ON AN INSTRUMENT FOR MEASURING THE STRAIN ON SHIPS' CABLES.*

By Thomas M. Gladstone, Esq., C.E., Assoc. I.N.A., Engineer to Lloyd's Registry of Shipping.

[Read at the Fourth Session of the Institution of Naval Architects, March 28th, 1863; the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

The investigation to ascertain, with certainty and exactness, the strain which is exerted by a vessel upon her cable, is a question to which much attention has been devoted, but it is still undetermined with any degree of precision: it cannot fail, therefore, to interest the Institution of Naval Architects.

The subject is one which has been hitherto a matter of speculation and doubt, regulated by no scientific data; and the proportions of the ground tackle have only been determined by the results ascertained from the failure of those in use. It is clear, therefore, that if by suitable and convenient machinery which will not interfere with the working on board ship, we can meet and give an answer to this enquiry, it must tend to do good service by leading to such exact proportions as will promote economy, and give increased security to both life and property, exposed to the dangers of the seas.

The power required to propel vessels of all forms of construction through water, has been the subject matter of many useful experiments, aiding to direct the designer as to the best lines for offering the *least* resistance to the fluid; and a law has been reached, which determines the proceedings of the naval architects thereon. In this, it was not needful to do other than prove their correctness in smooth water in the way which, I believe, was done by Mr. Scott Russell and others. The principle is, no doubt, familiar to the minds of many present.

That which is now proposed is a branch of the same subject. The object is to prove *what will be the action of a vessel, when riding at her anchor, even in the most extreme weather*—a datum which, heretofore, it has been deemed impossible to arrive at, notwithstanding how desirable the knowledge of it was. To solve this problem

* Received March 26th, 1863.

has been my study for some time past; and the *modus operandi* proposed by the "Hydrotestometer" will fully effect this purpose.

I propose, first, to point out the way in which my attention was drawn to it, and the curiosity of distinguished persons interested in the same: secondly, the steps that I have taken to bring it into notice, and to what extent the experiment should be carried out: thirdly, the description of machinery necessary; and, lastly, some arguments, which may be very fairly advanced in support of my views, while recommending its adoption.

First, then, I would observe that my attention was drawn to the subject from the earnest inquiry of certain distinguished naval officers, in their questions to witnesses before a Select Committee of the House of Commons, in the Session of 1860. That Committee was formed for the purpose of a general inquiry into the condition of the chain cables and anchors in the Merchant Service. It was stated in evidence *that they were generally in a most unsatisfactory state;* so much so, as to be nearly altogether untrustworthy. Exceptions however were found in those belonging to the vessels of a few leading shipowners, and the large steam-boat companies. In consequence of that Report, the Committee of Lloyd's Registry took the initiative in providing a remedy for that which was proved to be a *gigantic* evil. The steps for this purpose are now fully developed, in having two testing machines at the West India Docks, which machines give much satisfaction to the public, whose lives and property are so deeply concerned.

It was during the enquiry before the Select Committee, that certain questions were put which had special relation to the object of this Paper; and though struck out of the published Blue Book as not having a direct bearing upon the subject of enquiry, they made a strong impression upon me, when I considered the great vagueness of the replies. It was very pertinently asked by more than one naval officer, when allusion had been made to ships having parted from their anchors, "What strain do you suppose was on "the cable?" "Were there any *special* circumstances to cause its breaking?" "Can you "give even any *approximate idea* of the *force* exerted?" All of these questions were answered only in a most general, distracting, and, in some cases, discordant manner. As for example, "The strain was very great." "The ship must have exerted a very "great pressure upon her tackle." "It was very sudden and severe, indeed." It appeared to me that no satisfactory reply was given, and hence I was struck with the desirability of obtaining such data, if possible, by some properly adjusted, inexpensive, and scientific instrument. Finding this to be the condition of things, after the fullest enquiry among some of the most experienced seamen, I directed my attention to this question on which evidently so much natural anxiety was exhibited; believing too, that it was a question which could be practically determined.

Secondly,—At the time I commenced this investigation, I was professionally engaged at the Royal Dockyard, Woolwich, attending some experiments on the strength of chains. These experiments were made at the desire of some chain manufacturers, before a Committee of Lloyd's Registry and their head surveyors, the use of the testing machine having been granted by the Admiralty, on request of that Committee. It was then that I brought the question, now under consideration, to the notice of the Hon. Capt. Drummond, the Commodore of the Royal Dockyard; and after a full conference with him, and with the assurance of his co-operation, I submitted my plan to Admiral Robinson, the Comptroller of the Navy, who received it most cordially. I next addressed myself to the Lords Commissioners of the Admiralty, requesting permission to have the co-operation of the Commodore and the Master Shipwright, at Woolwich, in order that those officers might report upon the proposition. On the 26th of November, 1861, I received a letter to the effect, that I was at liberty to proceed to Woolwich Dockyard, and confer with the Captain Superintendent and Master Shipwright, in order that they might examine and report.

It was in January, 1862, that I met Commodore Sir F. W. E. Nicolson (Capt. Drummond's successor). The Master Shipwright had then copied the machine, and had laid it down in position, on a plan of the deck of a line-of-battle ship. Its merits were fully discussed, and it was left to the officers above referred to, to make their report to the Board. Along with that report, I gave the following memorandum:—

"In all matters of adaptation and construction the first point which must occupy "the thoughts of the engineer, is the *knowledge of the material* which the subject "requires; and the second, *the force to be overcome.*

"Keeping these principles in view, it will be at once admitted, that in regard "to *chain cables*, we have full and accurate information, so that, after *proof* and "*examination*, we know their exact qualities and powers; therefore, so far as the *material* "of which they are formed is concerned, we have all that can be desired.

"With regard however to the true action and resistance, or *the force of a ship* "*riding at anchor to be overcome*, we have but an imperfect acquaintance.

"Observation and experience have done much towards determining what that force "may generally be; while it has been thought impracticable to reach its solution with "that exactness and certainty which science would require. The practice has conse- "quently been so to approximate the *size* and *length* of cable, as observation alone has "determined as being suitable, having no principle of guidance, beyond the reasoning

" that, if a fracture has taken place through exposure to the weather and its violence, an " increase of size or length, or both, is necessary.

" Now, although it is right so to feel the way in relation to things for which we " are incapable of arriving at some law of precision, yet it is always both crude and " unsatisfactory, as well as often inconclusive and sacrificing—therefore, obstructive. " Nor does it, under the best conditions, satisfy the discerning and philosophic mind, " since it cannot meet the question,—What is the force to be overcome? in its full " necessity. From the want of this knowledge, great delay occurred in the introduction " of iron cables (in the place of hempen ones) into the Royal Navy.

" To the indomitable perseverance of the late Admiral Brown we are mainly indebted " for the use of iron cables; and thus, by his perseverance, he has left his mark behind " him, known and appreciated by all in the scientific world. But his work would have " been greatly facilitated, had he known of any simple means by which to test *the exact* " *force* it was proposed to contend with, and to overcome.

" It is to shew clearly how this force is to be determined, and to record the results " which is the subject matter of this Paper, and which are arrived at by the use of an " instrument, which I have denominated the 'hydrotestometer.' It is on the principle of " the hydraulic ram; and the one represented in Plate IX. is equal to, and will measure, " a strain of 200 tons upon a cable, which is far beyond the proof of the cables of the " *Warrior;* therefore, it is sufficiently powerful for any ship of the very largest class. " Although the dial is not arranged to indicate a strain greater than 200 tons, yet, at that " test the instrument would not be at more than one-third its strength. It occupies " a space of 6 feet by 3 feet, and stands 2 feet high. It can be placed in any convenient " position, being moveable; it has a bridle attached to it, and a stopper which can grasp " the chain cable, so that the whole weight shall come direct upon the instrument. The " strain is at all times indicated on a dial by means of a moveable pointer.

" By this arrangement, we are enabled to record the exact weight which is being " exerted upon a ship's cable *under all conditions of weather*, and thereby to determine " with accuracy what are the proper proportions to obtain security to life and property *on* " *shipboard*, by having such a disposition of chains and anchors, as shall be equal to any " contingency where there is holding ground. This instrument can also be applied, " when necessary, to test any other articles on board.

" It remains, therefore, to consider the limit to which it should be extended, and " also what would be its cost.

" I propose that two instruments should be placed one on board of each of two " separate vessels of the same class; for example—

	£	s.	d.
" Two for the *Warrior* class, which I estimate at £300 each - -	600	0	0
" „ for Frigates - - - £250 „ - -	500	0	0
" „ for Surveying Vessels - - £200 „ - -	400	0	0
" „ for Sloops of War - - - £150 „ - -	300	0	0
"	1,800	0	0
" Cost of fitting - - £25 „ - -	200	0	0
" Total cost for eight instruments - - -	£2,000	0	0

" And the effect would further be, to enable any vessel so fitted, when abroad, to test any " fibrous or other material met with, which would tend to determine their value (by " knowing their qualities), and be likely to aid in the introduction of new products into " the industrial arts."

The foregoing was the memorandum, which I gave to accompany the report of the Commodore Sir F. W. E. Nicolson and George Turner, Esq., the Master Shipwright, to both of which gentlemen my thanks are due for their attention and kindness.

Their report having been placed before the Lords Commissioners of the Admiralty on the 4th of March, 1862, I was informed that they had directed that the " hydro- " testometer should be carefully considered with regard to its practical utility," and it still awaits the opinion of other officers to whom it has been referred.

I, therefore, at this early period, bring it before this Institution; and I am most anxious that it should have the full consideration of such minds as are now drawn together, and such as can fairly and fully comprehend the whole bearing of this important question; and can determine (if the means are good) whether it is or is not a matter worthy of adoption. At the present time, it is a thing quite new and unknown. Its success depends upon the perception and acumen of those officers to whom it has been referred. I still trust that they will desire new light to be thrown upon the question, seeing that whatever will increase safety at sea makes a substantial addition to human happiness and property; and anything which tends to dispel uncertainty cannot but be a step in the direction of increased knowledge, which is the distinction, as it is one of the glories, of the period of human history in which we have the happiness to live.

In conclusion, I desire that the plan should have every just criticism, and that it should be regarded as springing solely from a desire to render our acquaintance more perfect with regard to the effects of the action which a ship exerts upon her ground tackle at periods of the greatest exposure to the elements.

In my humble judgment, new and striking matter will spring out of it in directions of which we are not now aware; and I shall be rejoiced if I find that I have enlisted further interest in this matter, as I have great hopes of doing, by bringing it before the Members of this Institution. I hope that, by its introduction to your notice, still further light will be thrown upon it. It may at first sight appear to some of small consequence; but if the same view of it be taken as followed my own deliberate thoughts thereon, it will be found rather to increase than to diminish in its practical character and importance.

There are no difficulties in detail but what can be easily overcome, so as to secure a sound result: nor can there be any fear that it would interfere with or obstruct the work of the ship in any way. When properly applied, we should be able to measure the force exerted upon the cables, just as we now determine the force of the wave, wind, and tide by instruments used for such purposes. It would give to the designer clearer views of the qualities of his models, and tend further to perfect the lines of every ship that may be built.

DISCUSSION.

Mr. Scott Russell, F.R.S., Vice-President, I.N.A.: There appear to be two sets of apparatus necessary for this operation: first, a dynamometer to measure the strength of cables, and also a means of measuring the resistance of the ship when lying at anchor. If these points are gained the instrument supplies what is wanted in the towing of ships. There can be no room for discussion on the advantages of having improved instruments for those purposes, though there are instruments at the present time which determine the strength of cables, as far as we require. Will Mr. Gladstone be good enough to give to the Meeting some particulars of this hydraulic dynamometer, and the means by which he renders it both so very delicate, and so very powerful in its action, because it appears to be more powerful than anything that has yet been done—will he be good enough to explain how he combines the extreme delicacy with the extreme power?

Mr. Gladstone, Assoc. I.N.A.: Fig. 1, Plate IX., shews a sectional elevation of an hydraulic ram with its attachment to a cable, its proportion and power as shewn by the indicator *a*, being equal to 200 tons pressure. Fig. 2 is a plan of the same, and shews the way in which it can be secured to the deck. It will be readily seen, that whatever pressure comes upon the chain will immediately act upon the indicator, which has a loose pointer to shew the highest amount of power exerted, while that which was acted upon by the fluid would oscillate continually as the strain increased or diminished.

It is further intended to lead from the ram a chain bridle to a direct connection with the cable in use, so that by slacking a foot or two off the "bitts," the whole weight comes upon the machine. As the instrument is supplied with a pump, when not used for these purposes, it could be made to test every rope yarn, hook or block on board, and even to set up the rigging or masts, besides numerous other appliances on shipboard, wherein great power is necessary to be exerted.

Mr. Scott Russell: Have you ascertained that that indicator has all the delicacy which you require?

Mr. Gladstone: Yes; and I have one of these instruments in use at Lloyd's Proving House. It is in the private office as a check upon the steelyard of the testing machine, so that I can tell at any time what they may have been doing during my absence, and whether or not the proper pressure has been put upon any cable. At the steelyard it can be done to one hundredweight, and by the indicator to a quarter of a ton, which is sufficiently near for all practical purposes.

Mr. Scott Russell: That is the only difficulty which we have hitherto had to contend with. An experiment of one *Warrior* towing another *Warrior*, with this apparatus, would alone give information worth far more than £300, the estimated cost of it.

ON THE NAVAL ARCHITECTURE OF THE EXHIBITION OF 1862.*

By Rear-Admiral E. Paris, of the French Imperial Navy, Assoc. I.N.A.

In one of the less frequented departments of the Exhibition were found numerous objects to which the public paid less attention than to the brilliant and less useful products displayed in other parts of the building. The tissues, jewels, and sculptures attracted crowds of admirers, whilst enlightened men examined with care the machines, tools, and products so remarkable, as the steels of Mr. Krupp and of Mr. Bessemer. If, in the main gallery, attention was attracted in approaching the great glazed East dome, it was only by the aspect of the mouths of terrible guns, round which were persons who expatiated on their size, whilst others sought a more intimate knowledge of those new and powerful means of destruction, unknown some time ago, and towards which modern science and industry have turned their efforts. They admired the perfection of the watch-like mechanism of the guns, as wonderful in its kind as that of the most regular chronometers, but few thought of the more important objects for which these formidable weapons were especially destined.

For it is not for armies, nor even for strong places, that such powerful guns are invented. Against men such guns are not required, but they have become necessary to attack or to defend structures that man has been able to produce, to which he has given a factitious life, and which he leads at his pleasure in all parts of the world. He has made those structures so gigantic that it is to fight them that the most powerful arms have always been invented. It is against Men-of-war that those guns are to be directed, and since iron plates have made them invulnerable, they have excited the spirit of invention to create arms more and more terrible. It is questioned which will prevail, the means of attack or the means of resistance; and the variety of guns is a proof of this struggle, the results of which are shewn in the plates of iron that have been pierced and torn by their shot.

But these guns have been made, I repeat, only for war-ships. To get an idea of

* This Paper was not read at the Meetings in March last, owing to the other Papers on the programme occupying the whole of the time; but it was thought desirable by the Council that it should appear in this volume of the *Transactions*.

these ships, one was obliged to penetrate into the hall where the various models were arranged, but upon entering this department the eye was disappointed: it fell from the reality of full size guns on little imitations which seemed to be playthings for children—it passed from giants' weapons to ships too small for the inhabitants of Lilliput. This contrast seemed to drive visitors away, and the department destined to the Navy was almost always deserted, even in this country, where everything concerning the Marine excites so eager an interest.

However, it represented the greatest revolutions of the greatest art of man. It resumed the long train of attempts and labours through which the actual maritime generation had passed; for seamen, who are not yet old, and who will probably spend a long time yet upon the water, had to contemplate, and to contribute towards forming four different and complete navies that appeared on the seas during the short space of thirty or forty years. It has been necessary to develope their details, to fit them to the new conditions, and to learn to use them, as the compulsion of science and industry wrought in them unavoidable changes. The representation of all these efforts—of millions spent every year by every nation—was enclosed in a space not much exceeding the gun-room of a man-of-war, or the sugar mill exhibited in the machinery annexe of the Exhibition. In that department was the expression of what fills the docks and covers the seas. In comparison with other industries, we saw there a remarkable but unavoidable contrast; ships could not be brought under galleries, like locomotive engines or looms, and even if they could they would not give an exact idea of the reality—they would only be shewing large wooden or iron buildings of different forms from our ordinary habitations or monuments—they would almost resemble the exhibition of a stuffed horse instead of a living one. It is, then, only at sea that we should see the ship, where she often struggles with the most dreadful elements, and where she is almost constantly victorious; it is, in fact, only in a heavy sea, and under full sail, that a ship is really appreciated. When she ceases to appear under such conditions, we can judge of her only by the inductions of experience, and by the impressions which similar constructions seen at sea have made upon the memory. It was, therefore, to the constructor and the sailor that these models were of passing interest; and that class was, indeed, composed of men sufficiently enlightened by their knowledge and long experience for their appreciation to be just, and profitable to listen to.

The most curious and complete collection was furnished by the British Admiralty, who had the happy idea to represent a sort of succinct history of naval construction, commencing with the *Great Harry*, which was built in 1488, and which, like other ships we knew of when we were young, was adorned with rich carvings. To this elegance

sueceeded the puritan simplieity of our large black boxes, marked with the prosaism of caleulation, and having an appearanee of stiffness, whieh, in spite of our imitations of past times, we find also in most of our modern eonstruetions. Exaet seienees seem nearly always to have driven away eleganee; but if the new ship is less elegant, she is better suited to her true warlike purpose. The model of the three-deeker *Howe* set forth this exaetly; it shewed to what a high degree of perfeetion and streugth the sailing ships had arrived, with what majesty they earried their large set of sails, and with what skill and agility the sailors eould manage and eontrol them in bad weather. It was a beautiful and grand profession—one that direetly daunted the elements; and it is no wonder that every old sailor regrets the change, and experienees painful impressions when he turns from the *Howe* to examine the eolleetion of iron-elad ships. But there is a kind of fate to whieh every one must submit. The impulse of modern industry demands sueh changes, and this impulse eannot be resisted.

The improvements effected in sailing ships, whieh we have just mentioned, form the first period of the history illustrated by the Admiralty models. Not mueh ehange was produeed by the introduetion of paddle-wheel steamers, in the time of the first applieations of Watts' admirable engines to marine purposes, beeause then they only produeed ships unfit for battle, sinee their wheels oeeupied the best position for the guns, and rendered the machinery liable to be disabled by shot. In vain were the guns disposed of in various ways, for these vessels were only good as transports; and the old ship preserved unrivalled her title of man-of-war. This was the seeond period, and was represented at the Exhibition by some models of paddle-wheel vessels, espeeially that of the Queen's yaeht, whieh was remarkable for her perfeetion. This period lasted till the serew-propeller, applied to war-ships, deeided the question in its own favour, eombining in the same vessel all the qualities of the sailing ship and the steamer, without interfering with any of the fighting parts, and this at the eost only of a part of the spaee apportioned off for the provisions and water.

The early attempts at this transformation—the third period—were not sueeessful. Only indifferent engines were at first obtained, and the introduetion of new meehanism under water presented many diffieulties. But the solution of the problem was ultimately made by M. Dupuy de Lôme in the *Napoleon*, whieh ship earried 90 guns at the rate of 12 knots, and realized the remarkable prineiples pointed out about the same time by Captain Pellew Halsted.

In this type of ship, it was thought that absolute perfeetion was attained, since we had eombined in the one ship so many desirable qualities—a great spread of canvas, powerful artillery, and engines powerful enough to enable her to outstrip any paeket, to overcome the obstaeles of wind and sea, and, in some eases, to render assistanee to other

ships by towing them. Unless somebody made an unexpected discovery, or invented some more powerful propeller than the steam-engine, in proportion to its weight, M. Dupuy de Lôme seemed to have produced the type of vessel destined to play the principal part on the sea, and to be substituted in time for every other. There would not, indeed, have been any material change for a very long time if solid shot had continued to be the weapon used at sea; but the adoption of shells showed very forcibly that fights between wooden ships would be so terrible that they would be destroyed before they had decided the political questions of which they were the champions. Sinope was an illustration of this, for solid shot would never have so quickly destroyed the Turkish fleet. Moreover, during the war with Russia, it was the land alone that was to be attacked, and its batteries being as insensible to shell as to shot, became the more formidable, so that wooden ships were relatively weakened. These events induced us to refer back to experiments made in 1848, to know the necessary thickness of iron to resist solid shot; and it was then seen that iron, 10 centimètres thick, was necessary to resist the projectiles then in use. At this time it was considered very desirable to attack the island of Cronstadt, which was surrounded by shoals, and accessible only through shallow channels, and the very small draught of 2 metres 60 centimètres was adopted. This added to the other difficulties attending a first attempt, the serious one of a small draught of water, with that of carrying unwonted masses of iron. To attack, at a near distance, formidable fortifications, it was necessary to cover the vessels with 10 centimètres of iron, and with a bomb-proof deck. As the ships (French) were to carry 20 50-pounders, their powder and projectiles, stores, and a 300 horse-power engine, it was found impossible to keep to the fine lines and sharp bow which were best fitted for speed, and for the favourable action of the propeller; and it became necessary to build great rectangular parallelopipedons, rounded at their angles. Three of these floating batteries, which were more formidable than those used by the Roman soldiers with their shields, advanced slowly towards Kinburn, and soon silenced its batteries. These vessels were the *Lave*, *Dévastation*, and *Tonnante*, and their names deserve to be preserved in a similar manner to that of the *Rocket*, in the history of steam-boilers.

Thus, the fourth period of the history of the navy was commenced, and it may, with reason be named the age of iron, so much did it banish poetry, and so much did it give its ships the aspect of reptiles, especially when compared with those noble ships that were so justly called Men-of-war, but which, however, will be compelled to yield before those creeping things, as much to be dreaded as if they were venomous. Iron-clad ships are, however, to be accepted: they have become a necessity of the time; and as soon as they appeared, it was easy to see that they would require, at least, as much art for their construction as the old ships. Iron-clad ships presented to the shipbuilder new problems,

the basis of which were uncertain from want of previous experience: they showed to the sailors that the era of wooden ships was ended—that one of those ugly and shapeless ships alone would be a match for a whole fleet of wooden vessels. These floating batteries, then, presented a fact which, though unobserved by the public, was not less conclusive than the destruction of the *Cumberland* by the *Merrimac*, and the so sadly ended feats of the *Monitor*.

But it may be said that they resolved only part of the problem—the one that really belonged to artillery—since their speed was extremely low, and they would have been in great peril had they encountered a severe storm at sea. They possessed only force and resistance of speed; and in other indispensable qualities of a sea-going ship, they were wholly deficient. Again, it was M. Dupuy de Lôme, who undertook to launch thoroughly iron-clad sea-going ships, and to give them a speed equal to his preceding constructions: he succeeded by keeping down the weights of masts, decks, &c., and suppressing upper guns that the ship might carry its iron-plating in safety. In its simplicity it was the thought of a statesman, and it was that simplicity which rendered the execution of the plan easy, and hastened its adoption; for when a great question presents itself with all the difficulties of novelty, it must be brought back to its simplest expression, that it may have all the chances of a ready execution.

It was, perhaps, to be regretted that the model of *La Gloire* was not at the Exhibition, but it would only have satisfied curiosity, and afforded pleasure at having seen a novelty which so interested the public. For in her case, the first thought is all: when this is known the details come of themselves, and the important result is a fast steam line-of-battle ship, without her upper battery, with many useless weights suppressed, and in which all that is so suppressed is compensated by the weight of iron plates. This is a matter as simple as the egg of Christopher Columbus, and the engineer who had built the first fast screw line-of-battle ship, naturally succeeded in the construction of the first iron-clad frigate. It is readily seen, that to execute this scheme it was necessary to make some sacrifices, but, surely, complete invulnerability is worth the loss we sustain in coming from 90 guns to 34 guns, especially when neither speed, coals, nor provisions is lost, but only masts, which even in wooden ships would be fatal in their fall by the yards and rigging coming in contact with the blades of the screw. For at sea there is no quality which has not its weight, and hence its value; and to conceive this let us remember that force is represented by the guns, the men, and the provisions: the speed, by the power of the engine, at the rate of the cube of that speed: the radius of action, by the quantity of coal; and finally, the weight of the ship itself that must carry all these things.

But it is of no use to recall the difficulties of these new questions, especially in the

presence of our Vice-President, Mr. Scott Russell, who has described them in so lucid a manner, that we have only to remember his remarkable comparisons to understand the extraordinary compromises which must be made in order to secure each new quality. But, however, it is very natural not to stop when we look at a noble object, and to strive our utmost when we see a chance of obtaining it. It is to this ardent desire for improvement that most of the progress of our time is due, and that so many bold attempts must be attributed. Locomotives, the seas being travelled over with the help of steam, the speedy packets outstripping each other, the *Great Eastern* a reality, the Isthmus of Suez crossed—all these wonders of our period cause us to think anything possible. Indeed, with such precedents, it is always allowable to wish for more than exists at the time; and many things tend to make progression easy. Abundance of money, labour sufficient to execute the greatest works, iron enough to permit of constructions of the largest dimensions, and engines, the limits of the power of which is not yet known. Some persons may say that we have only to desire, to have, and that we have arrived at the condition of spoiled children, who, certain of obtaining, sometimes ask for impossible things. It is, however, the profusion of means of execution that has led to such a gigantic construction as the *Northumberland*, and to the uniting in her of so many good qualities; and yet, these qualities have not arrived at their limits. That large ship, represented by the beautiful model of Messrs. Mare & Co., will be surpassed as soon as a larger sum of money be applied to the construction of a new vessel. No one knows the limit, because the limit of industrial credit and production is unknown.

These ideas lead to a natural question—Why are we now labouring under these indecisions, in the midst of a steeplechase for an ever-growing perfection, when some time ago we were satisfied with what we had, without anticipating anything beyond? It is because formerly there were natural limits on account of the materials that were used—because a greater size of sails would have been accompanied with a number of difficulties in their management, as we could no longer have used men enough at a time. For, if on the deck a great many hands are used, and they are able, all at once, to execute the same work, it is not the case when the sails have to be reefed and furled from the yard. If the dimensions of the vessel were doubled, we might send double the number of men on the yards, but the sails' surface would be four-fold, and the canvas and leech ropes bigger, and thus each man's work would be much greater. Thus the three-decker was a superior limit that would not be passed, while she was more difficult to manage than frigates and smaller ships. But now, a few men, merely to throw coal into the furnaces, together with a few mere boys, are sufficient to manage such a ship as the *Great Eastern*, since with them we can control the valve gear of her enormous engines, to move or stop them. If Mr. Cunningham's method of reefing had been sooner

known it would have been more extensively applied to ships of war; for it has rendered the management of large clipper ships very easy.

On looking at the model of the *Howe* which was in the Exhibition, we could have remarked that she was the *ne plus ultra* of sailing ships, but on looking up at the gallery we perceived the model of the *Great Eastern*, and we could not help recollecting that that piece of polished wood represented a ship, 680 feet long, and of 30,000 tons displacement. This comparison instantly showed how the engines, and the iron construction had extended the power of man at sea.

To many models of old construction, the Admiralty added others of new ships in course of building; and in examining them—the fine models of the *Northumberland* and the *Warrior* being among the number—we could not fail to see how the rapidity of the march had been appreciated, since, in spite of the difficulties of an iron coating, or the inconveniences of an imperfect protection, the adoption of long proportions which are acknowledged necessary to the speed of vessels had been decided upon. We were struck, too, with the difference of the dimensions and disposition of the iron coating to satisfy the various conditions of service and navigation. These differences were shown by models of all the iron-coated ships, from the shot-proof battery of the *Trusty*, or rather from the *Warrior*, which in fact opened the era of the new constructions in England. This variety showed how the new question had been represented in every shape, and what enormous proportions we were compelled to give, since to attain a speed of 14 knots, and to enable the ship to go a good sea-voyage, a length of 400 feet was given to the *Northumberland* and the sister vessels: thus she will be almost as long as two of the old three-deckers, and will weigh about 10,000 tons, to carry only forty protected guns. It is, indeed, in such vessels as these that we see the extent of the cost of invulnerability and speed combined.

The *Prince Consort*, and others that are to be entirely protected, have much smaller dimensions, and seem to come nearer the French type. The result in their case will be a diminution of speed, and a lessening of the radius of action, expressed by the number of days a vessel will be able to steam, which will of course depend upon the quantity of coals in the bunkers. If speed is to be preserved at any rate, an examination of those models will show that complete protection must be abandoned; and this sacrifice, if too much extended, would cause ships which are better adapted for speed in a heavy sea, to lose, when in action, almost all the advantages of a partial iron-coating. This, Captain Halsted so well demonstrated that it is almost needless to speak of it.

It is, also, very likely that the interior water-tight divisions would not supply the place of the plates, since they do not protect the vital parts; and it is better to prevent the water getting in than to risk its entrance, however confined it may afterwards be

in small places. If we come below the considerable dimensions of the *Prince Consort*, we see directly that to fulfil special aims we must forsake or lessen these qualities; moreover, the speed is necessarily reduced, as well as the quantity of coal, and if we admit that the protected guns are the principal things, and the rest accessory, the result is that the former diminish much more than the latter, and we have less strength in proportion to the cost. There is, then, a natural difficulty that may be overcome by great talent on the part of engineers, but it will always leave traces of the kind of law that rules the proportions between the size of the ship and the service it renders.

These are found to be the reasons that led to the building of the *Connaught* and the *Leinster* as long as the *Warrior*, to enable them to go very fast for a very short distance; and the *Great Eastern*, which weighed almost as much as seven old three-deckers, to be able to go direct from England to Australia. These are kinds of natural laws that influence the construction of all vessels, whatever may be their destination, though they are not yet settled in any positive manner. If, instead of diminishing the strength in building smaller ships, we wish to preserve the guns and iron-coating, we must lose speed, and, by degrees, we shall come to the floating batteries. In following this course, that is in coming down from all the advantages to the inconveniences of a smaller size, we arrive at the fast floating batteries which are a medium class; and they are sufficiently remarkable to admit of a few remarks upon them:—They are iron vessels, built at La Seyne near Toulon for the Italian Government; their bottoms are flat and their extremities are sharp, their length is 65 metres, breadth 13 metres 60 centimètres, depth 8 metres 25 centimètres, and the displacement is 2,725 tons. Their armament consists of twenty-four Piedmontese 40-pounders, and of six 80-pounders. The nominal horse-power is 600, and the speed in the experiments has been 11 knots. They are very handy and steer very well, but they roll much.

Near the models above-mentioned, there was one shewing the remarkable arrangements adopted by Captain Coles, who, during the Crimean War, had been surprised at the number of men killed at Kinburn, by the shot entering through the port-holes. To protect the gunners as much as possible, he has invented, as every one knows, the ingenious contrivance, known as the Cupola Shield. Nothing, indeed, will resist more, and be stronger than those oblique iron surfaces in which are left spaces just sufficiently large to enable the muzzle of the gun to be run out. This principle of Capt. Coles's has been extensively applied by the Americans during the present war, and its fitness proved, at least, for the smooth-water rivers. If doubts now remain, it is only on the sea-going qualities of ships so little elevated above the water in proportion to their weight. It is probable that the cupola ships will be considered powerful ships for defence: they represent a medium between the great constructions undertaken by the Admiralty, and

those proposed by numerous inventors, of whom it may here be necessary to say a few words.

It is remarkable to observe that in all the inventions of persons unconnected with the navy, the principal thought seems to be of defence. The numerous models have various oblique or rounded surfaces in order to glance off the shock of the shot; and they also suggest protection to the propeller by carrying it before the sternpost. I noticed in one instance that the propeller was sheltered by a casing, so as not to present any vulnerable part. Some even have a screw propeller at each end, in order to accelerate the turning of the vessel. But among all these things, that which strikes one, is the total want of nautical qualities. From their form, most of the ships built after those models would roll immensely, and owing to their little elevation above water, and their great weight, they would be nearly always under the waves in a heavy sea. It may be said that the striking features of the Admiralty's ships were speed and sea-going qualities, which fitted them for attack, and enabled them to render assistance to far-distant colonies, whilst, on the contrary, the public only sought to produce iron fortresses—structures, which, though moveable, were not at all fitted for sea-going purposes.

In referring to these constructions, we must not forget to mention the sharp bows. These were of a different shape from those ordinarily used, and were made for the same purpose as the prows of antique galleys. With these bows it was intended to use the enormous strength of the engines and the heavy mass of the ships to crush and sink the enemy; for there has been of late so much care taken to protect ships, and so much skill employed to make them impenetrable to shot, that invention has at length turned to other means of destroying them. A singular contrast of human activity swells the caprice of our ideas. To make ships invulnerable, immense sums of money are annually spent, and certain qualities diminished; and at the same time we are endeavouring to contrive other means to destroy them. But whatever may have been the first cause for this change in the stem, a distinguished officer of the French navy (now Admiral Labrousse) did, a long time ago, define its use in the first book which was published on the Screw-propeller, in 1843. His idea gained favour, and a sharp prow was put to the French ship, *Magenta*. There are probably good reasons for the adoption of this plan; but I must own that, without any experiments, and, being guided by my own opinions, I have, till now, had little confidence in such a projection. It seems to me that before adopting it, it would have been wise to try the method of using it—to have endeavoured to establish by results some rule of fencing for these new knights of 6,000, and perhaps we may soon have them of 10,000 tons weight, and which will require for their field a vast extent of water, in order that they may be able to turn and advance at a proper speed. But if methods of ramming be devised, other methods will be invented to avoid

them, or to render the blows so oblique that they will be more dangerous for the sharp bows which deliver them, than for the sides covered with thick plates and strongly backed with wood. If the prow were to penetrate a vessel whilst she was in motion, would there not be chances for the attacked vessel to tear away that prow with the adjacent framing? If the shock be direct, what will become of the internal arrangements of the ship? There are the boilers, which, if thrown an inch out of their place, will burst their pipes; and which, when its sides are forced by the pressure, will in a moment receive the shock of the inertia of the water. There is then a series of unsolved questions upon which every one expresses his opinion, as I have just done, without throwing much light upon them.

It would take too long to review all that the Exhibition presented in reference to the question which now occupies our attention. It would be more fitted for publications, which every one might read at leisure. It will suffice to present general considerations on the probable consequences of the great maritime reconstruction which is taking place.

One of the first questions is,—Are the armour plates which are used a sufficient protection? On the one side, the inventors of guns pretend to pierce every thing: and, on the other, those who build ships build them in the hope that they will resist the shot; and thus, large sums of money are spent upon studying the question without advancing its solution. I believe, in reference to what already exists (for on such matters it is impossible to know the changes that will take place), that we may admit for the moment that with chance of failure in the aim, or wasted or oblique shots, the protection is now sufficient, and that it will be very difficult to carry more weight without considerable inconvenience in navigating the vessel.

It is true that guns have been invented, more terrible than the old ones, but at the same time they have been rendered much more susceptible to injury, especially when they have to be fired for a long time. I do not mean to say that, with the talent and perfection of workmanship of our period, we shall not succeed in strengthening this artillery.

It would, perhaps, be proper to consider which are the materials better adapted for the new constructions; but this question has been so much debated that it is to the public, and not to an assembly of shipbuilders, engineers, and sailors, that we should direct such explanations. It may be said, however, that this question is so far from being decided, that every nation uses what its resources can best supply, and what most suits the convenience of its administration. Time will probably settle this matter, at least, so far as expense and durability are concerned.

The question that belongs more directly to sailors and constructors, is the appreciation of the manner in which these ships will behave at sea: as yet, they have not

been sufficiently navigated to go through the terrible chances to which a ship is sometimes subjected when out in open sea. Of these constructions, we have not had that long experience which enabled us to bring our fine old line-of-battle ships to confront, without peril, all that fate reserved for them in their long travels. The position of the weights has been changed: instead of disposing them in the higher parts of the ship, they have been contracted on the sides, which have been furnished with a considerable dead weight, like the leaden clock of the hell of Dante. These changes certainly exert a great influence, for we recollect how those we effected in our former ships influenced the speed so much, that there were instances of some ships gaining, and of others losing that precious quality. This is not perceived now, because, instead of having the same amount of sail set, which, with the same wind, would be an equal moving power, and consequently fit for exact comparisons, we have an engine of a very irregular force. A leak in the slide, a change of coal, and even unskilful stokers diminish the speed, and without the cause being thoroughly appreciated; consequently, the influence of the weights receives no attention, and this basis fails to show the one exerted on the sea-going qualities, and thus, we roll more than ever in every kind of ship. Some attribute the rolling to the greater length of the vessel; but there is a natural law to which we must yield, to determine the weight in proportion to the displacement. Why does a spar or a yard cease to roll, and lie motionless, when there is on one side some piece of iron that puts the centre of gravity further from the centre of figure, whilst those same pieces of wood may be turned with a finger if they have no lateral weights and are equally balanced? Does it not indicate, that there is no stability of form, and that the addition of a large nail gives only stability of weight, which suffices to give lateral immobility on the waves? In spite of such comparisons, which are apparently very simple, the question of rolling must still be very obscure, since vessels roll more than ever. There are many sailors who still remember those old ships with a "tumble-home" side, which stood so well at sea; and the "tumble-home" must have been considered very necessary by our fathers, for not only were ships thus constructed, but the corvettes à Barbette were similarly formed. The old frigates of Sané have been reproached for inclining too easily—for preventing the firing through want of ballast; but, with the few sails we are now confined to, and these being furled during a fight, this difficulty is no longer to be feared. Every weight has been lowered: the engine and the boiler itself are a natural ballast, and there is too much stability for the ship to be upset in a squall. The ships that have been built, and which have not had ballast, seem to have proved, by the excess of their movements, that the stability, being dependent alone upon the great differences between their forms above and under water, was one of the chief causes of the violent rolling. But upon these questions I think we can express only vague opinions, and it is most unfortunate that we want a basis for exact conclusions. When

a liquid ceases to be at rest, its laws are almost unknown; and those of the sea are still less understood. What is this small hill that advances so rapidly, to be succeeded by another, and by every following one? It seems to travel faster than the most rapid packets, it upsets everything in its passage, and no one of its molecules has changed place—they only went up and down in time, with an almost perfect isochronism. We have not yet made a dynamic wave; how then are we to make dynamic rolling? Experience alone must guide us in this obscurity, and lead us, if not to exact measures, at least to a sufficient estimate of the conditions in which a ship floats. As the variety of the forms of ships prevents our knowing the partial influences, why not divide one into sections that we may ascertain what are the influences on each? Do we not recur to springs to know the influences of the inertia of the weight, and express them by diagrams? There is an extensive horizon of useful observations, but it is still very obscure; and if there exists an Institution worthy to undertake the solution of them, and bring them to a useful end, it certainly is the Institution of Naval Architects, for on such matters it has united the separate attempts, and brought about a public discussion of results, which are the best means towards advancement. The various Institutions of England have given great proof of this, and if there are a Lifeboat Institution, a Steam-ship Performance Committee, and a Meteorological Society, who announce to sailors the winds that they will most probably meet with at sea, would not a Ship Sea Performance Committee have many chances of rendering signal services to every builder and sailor; and they would not then have to appeal to other nations that are also occupied with nautical questions.

But, in conclusion, I perceive that, led by an affection which I may say I have always felt for the profession of a sailor, I have forgotten myself by seeming willing to give lessons to those who are masters of my subject; for my ideas have been advanced before the constructors of many fine ships of all kinds—before gentlemen who have invented and propagated iron constructions which have obtained extraordinary speed—before the constructors of the *Persia*, *Himalaya*, *Great Eastern*, *Leinster*, *Connaught*, and many others. A sailor's part is to use, to the best of his ability, the ships that have been constructed for him, and to know them as a horseman, who, after long travel knows, and is able to judge of the horse which he has mounted.

ON THE COMPARATIVE STRAINING ACTION OF DIFFERENT KINDS OF VERTICAL OSCILLATION UPON A SHIP.*

By W. J. Macquorn Rankine, Esq., C.E., LL.D., F.R.S., Assoc. I.N.A.

Section I.—*Object of the Investigation.*

1. I have been induced to write this Paper by the publication in the 3rd volume of the *Transactions* of this Institution, pages 38, 39, and 40, of some remarks by Mr. Froude, in which he questions the accuracy of the commonly-received opinion, that the vertical oscillation of the centre of gravity, or the "bodily rising and falling" of a ship of the form known as the "Symondite" constitutes an "uneasy motion:" that is, as I understand it, a motion that produces peculiarly severe stress on the structure of the ship. For brevity's sake, I shall throughout this Paper call the kind of oscillation in question the "*Dipping Motion;*" because it consists in an alternate dipping into, and rising out of, the water.

2. Another kind of vertical oscillation, or bodily rising and falling, whose straining effect I shall compare with that of the dipping motion, is the vertical component of the motion of the ship when she accompanies bodily the motion of the waves. This kind of motion, for brevity's sake, I shall call the "*Heaving Motion.*"

3. Mr. Froude correctly states (p. 39), that the intensity of the stress produced by a given oscillation is proportional to the extent of the oscillation and to the square of its frequency (or to the inverse square of its periodic time); and that if we consider the permanent straining effect of a series of oscillations as depending jointly on the intensity of the stress and on the frequency with which it is repeated, that effect will be proportional to the extent of the oscillation and to the cube of its frequency (or to the inverse cube of its periodic time).

4. The dipping motion of a "Symondite" ship originates, as is well known, in the difference, for a given angle of roll, between the "solids of immersion and of emersion;" and the extent of that dipping motion, though not necessarily equal to, at all events

* This Paper was not received in time to be read at the Meetings; but it was determined upon by the Council that it should appear in the present volume without having been previously read. It was received March 27th, 1863.

depends upon, the depth found by dividing that difference by the water-line area. That depth, indeed, is very nearly one half of the exact extent of the dipping motion which would be produced by a very sudden roll. If we call the depth found by dividing the displacement by the water-line area the "mean depth of displacement," then half the extent of dip for a very sudden roll is less than the mean depth of displacement very nearly in the same proportion that the difference between the solids of immersion and of emersion is less than the displacement. In algebraical symbols, let V be the displacement, A the water-line-area, $\delta = V \div A$, the mean depth of displacement, D the difference between the solids of immersion and of emersion, and z half the extent of dip, or the "half dip" as it may be called: then, for a very sudden roll,

$$z = \frac{D}{A} = \frac{D}{V}\,\delta, \text{ very nearly.} \quad (1.)$$

5. The extent of the dipping motion, as given by the preceding rule, is in every case small as compared with the extent of the heaving motion. In a well-proportioned ship, the rolling motion is less frequent than the heaving motion (which keeps time with the waves). Hence, if the periodic time of the dipping motion were the same with that of the rolling motion (that is, a dip and a rise to each double roll), there could be no doubt of the accuracy of Mr. Froude's conclusion, that the straining effect of the dipping motion is trifling.

6. But the dipping motion has a periodic time of its own, which is always considerably shorter than the periodic time of the rolling motion, and which may be considerably shorter than that of the heaving motion also. It is quite possible, therefore, that the greater frequency of the dipping motion may make up for its less extent, so as to make its straining effect on the ship considerable.

7. It is further to be remarked, that the possible extent of the dipping motion is not limited to the double of the depth stated in Article 4th, and given in equation 1. That depth is one-half of the extent of the dipping motion, which may be set going by a *single sudden roll*, and which, even though the rolling should stop, will be followed by a series of dips of gradually diminishing extent until the motion is stopped by the resistance of the water. When a "Symondite" ship makes a series of rolls, each roll sets going a fresh series of dipping oscillations; and should the periodic time of rolling happen to be double, quadruple, or any *even multiple* of the periodic time of dipping, so that each roll coincides with the rising part of the previously existing dipping motion, the extent of the dipping motion may go on continually increasing to an amount limited only by the resistance of the water; just as the extent of the rolling motion of a ship may, as Mr. Froude has shewn, go on increasing when its periodic time coincides with that of the waves.

8. In the following approximate investigation of the comparative straining effects of dipping and heaving oscillations, the dipping motion is treated as if it, as well as the heaving motion, followed the law of isochronous oscillation, like a cycloidal pendulum. That is not exactly the case; but the error is unimportant as regards the present question.

Section II.—*Straining Action of Vertical Oscillations in General.*

9. When a ship, or any other heavy body, is supported in any manner, the stress on its several parts is the effect of the amount and distribution of the weight, and of the manner in which it is supported; and if, without altering the manner of support, or the distribution of the weight, we alter the *amount* of the weight in a given proportion, by altering the weight of each particle in the same proportion, then the stress on each part of the body is altered in the same proportion also.

10. When a heavy particle is at rest, or moving uniformly in a straight line, the neighbouring particles act upon it with a force equal and opposite to its weight, so as to support it; and it rests upon them with its weight simply. When the same heavy particle undergoes a varying motion, the action of the neighbouring particles upon it is the resultant of a force equal and opposite to its weight, and of the force required to vary its motion; its reaction upon them is the resultant of its weight, and of a force equal and opposite to the force required to vary its motion; and its tendency to produce stress amongst the other particles of the body is the same as if its weight were changed into that resultant reaction.*

11. Hence, when a heavy body, supported in any manner, undergoes a simultaneous and equal variation of the motion of all its particles (as in the bodily oscillations of a ship), the straining effect is the same as if the weight of each particle, and of the entire body, were changed into the resultant of that weight, and of a force equal and opposite to the force required to produce the varied motion.

12. When the motion in question is an isochronous vertical oscillation, the change in the resultant reaction of each particle, and of the entire body, is equivalent to an *alternate increase and diminution of the weight* in a proportion given by the following rule:—

As the length of a simple pendulum which keeps time with the oscillation, : is to half the extent of the oscillation, :: so is the real weight : to the apparent variation of weight (which is alternately added to, and subtracted from, the real weight). And further,

* This is a particular case of the principle known by the name of D'Alembert, which Mr. Froude, Mr. Crossland, and myself, have already applied to the motion and action of waves.

: : so is the stress in equilibrio, : to the greatest increase of stress produced by the oscillation.

13. The preceding principle, expressed algebraically, is as follows:—

Let T be the periodic time of a complete oscillation, or double-swing, in seconds; l, the length of the corresponding simple pendulum; x, half the extent of oscillation; f, the ratio which the reaction due to the oscillation bears to gravity; so that the apparent weight of a mass, whose real weight is 1, becomes alternately $1+f$, and $1-f$: then $l = \cdot 8154$ foot $\times \mathrm{T}^2$; and $f = \frac{x}{l} = \frac{x \text{ in feet}}{\cdot 8154\ \mathrm{T}^2}$, (2); and this quantity is a measure of the *comparative intensity of stress* produced by different kinds of oscillation.

14. But, as already stated in Article 3, the permanent straining effect is probably proportional to the intensity of the stress and its frequency jointly. Hence the measure of the *comparative permanent straining effect of different oscillations* is the following quantity:—

$$\frac{f}{\mathrm{T}} = \frac{x}{l}\sqrt{\frac{\cdot 8154}{(l \text{ in feet})}} = \frac{x \text{ in feet}}{\cdot 8154\ \mathrm{T}^3} = \frac{\cdot 903\ x}{l^{\frac{3}{2}}}. \quad (3.)$$

Section III.—*Application to Heaving Motion.*

15. The periodic time of the heaving motion produced by the waves is the same with that of a pendulum whose length is to the length of a wave as the radius of a circle to the circumference. If, therefore, using the same notation which has been employed in treating of the motion of waves, we take R to denote the radius in feet of the "rolling circle" whose circumference is the length of a wave, so that the length of a wave is 6·2832 R, we shall have, in the case of the heaving motion,

$$l = \mathrm{R}; \text{ and } \mathrm{T} = \sqrt{\frac{\mathrm{R}}{\cdot 8154}} = \frac{\sqrt{\mathrm{R}}}{\cdot 903}. \quad (4.)$$

16. The half extent of the heaving motion, or "half heave" as we may call it, is the mean radius of the orbits of the particles of water amongst which the ship is immersed; which being denoted by r, we shall have to make, $x = r$ (5.)

17. If those values of the simple pendulum, periodic time, and half-heave be substituted in equations (2) and (3), the following results are obtained: proportionate stress due to heaving motion, $f = \frac{r}{\mathrm{R}}$; (6.) Comparative straining effect, $\frac{f}{\mathrm{T}} = \frac{\cdot 903\ r}{\mathrm{R}^{\frac{3}{2}}}$. (7.)

18. As a numerical example of the application of those formulæ, let us take the case of heaving motion produced by waves 512 feet long, the vertical extent of motion being 20·4 feet. Then we have the following results: radius of rolling circle, $\mathrm{R} = \frac{512}{6 \cdot 2832} = 81 \cdot 54$ feet; periodic time, $\mathrm{T} = \frac{\sqrt{\mathrm{R}}}{\cdot 903} = 10$ seconds; half-heave, $r = \frac{20 \cdot 4}{2}$

$= 10{\cdot}2$ feet; proportionate stress, $f = \frac{r}{R} = \frac{10{\cdot}2}{81{\cdot}54} = \frac{1}{8}$ nearly, or ·125; comparative straining effect, $\frac{f}{T} = \frac{1}{8 \times 10} = \frac{1}{80}$, or ·0125. The value of f shews that the stress produced by the heaving is equivalent to an alternate apparent increase and diminution of the weight of every part of the ship to the extent of one-eighth part of the real weight; and this is repeated once every ten seconds, or six times in a minute.

Section IV.—*Application to Dipping Motion.*

19. When the causes of irregularity in the dipping motion of a ship are neglected (which is allowable in the present inquiry), that motion is found to keep time with the oscillations of a pendulum, whose length is the "*mean depth of displacement*" already mentioned in Article 4, as being computed by dividing the volume of displacement by the water-line area. For the demonstration of that proposition, it is sufficient to refer to Duhamel's "Traité de Mécanique", Part 2, Arts. 159, 160. Hence in the formulæ, we are to make, $l = \delta = \frac{V}{A}$, (8.); and taking T′ to denote the periodic time of the dipping oscillations, $T' = \sqrt{\frac{\delta}{\cdot 8154}} = \frac{\sqrt{\delta}}{\cdot 903}$ (9.) The value to be given to the half extent of oscillation x is of course the half-dip, z.

20. Hence the following results are obtained: proportionate stress due to dipping motion, $f' = \frac{z}{\delta}$; (10.) Comparative straining effect, $\frac{f'}{T'} = \frac{\cdot 903\, z}{\delta^{\frac{3}{2}}}$. (11.)

21. As a numerical example of the application of those formulæ, let us suppose the mean depth of displacement (δ) to be 13 feet, and the total vertical extent of the dipping motion to be the same as in an example mentioned by Mr. Froude in a note to his remarks, *viz.*, 9 inches, or ·75 of a foot. Then we have the following results: periodic time, $T' = \sqrt{\frac{13}{\cdot 903}} = 4$ seconds nearly; half-dip, $z = \frac{\cdot 75}{2} = \cdot 375$ of a foot; proportionate stress, $f' = \frac{z}{\delta} = \frac{\cdot 375}{13} = \cdot 029$ or $\frac{1}{35}$ nearly; comparative straining effect, $\frac{f'}{T'} = \frac{\cdot 029}{4} = \cdot 00725$ or $\frac{1}{140}$ nearly. The value of f' shews that the stress produced by the dipping motion is equivalent to an alternate apparent increase and diminution of the weight of every part of the ship, to the extent of one thirty-fifth part of the real weight, or thereabouts; and this is repeated once every four seconds, or fifteen times in a minute.

Section V.—*Effects of the Heaving and Dipping Motions compared.*

22. In the numerical examples given in the two preceding sections, it appears that the straining action of the dipping motion is by no means trifling in comparison with that of

the heaving motion produced even by a wave of considerable height; being less only in the ratio of 725 to 1,250, or 4 to 7 nearly. If the extent of the dipping motion had been supposed to be about 16 inches instead of 9 inches, its probable straining effect on a vessel of 13 feet mean depth of displacement would have been found to be *equal* to that of a series of waves 512 feet long, heaving the ship up and down through 20·4 feet; or, had the alternate rise and fall produced by the waves been taken at about 12 feet, their straining effect would have been found to be no greater than that of the dipping motion to the extent of 9 inches.

23. Those results are in accordance with the statement already made in Article 6, that it is possible that the frequency of the dipping motion may make up for the smallness of its extent, so as to make its straining effect considerable; and in conjunction with the possible increase in extent of the dipping motion described in Article 7, they confirm the prevalent opinion, that the so-called "Symondite" form, which tends to produce dipping oscillations, is a cause of "uneasy" motion, and of undue strain upon the ship.

[Note, *added on the* 19*th September*, 1863.]

It may be remarked (though not strictly belonging to the subject of the present Paper), that the "Symondite" form tends to make the heaving motion itself more severe; because, as the mean depth of displacement is less than in a ship of the same displacement and draught with vertical sides, the "Symondite" vessel is more under the influence of the upper layers of water, whose motion is more extensive than that of the lower layers.

ON ISOCHRONISM OF OSCILLATION IN SHIPS.*

By W. Froude, Esq., Assoc. I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 27th, 1863; the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

The equations of motion for a ship rolling in a sea-way, as given in my Paper, *Trans. I.N.A.*, 1861, were rigorously applicable only to a ship which would perform isochronous oscillations in still water; and objections have been expressed to this condition as impairing the practical value of the equation by too greatly limiting the range of its fair application. It is therefore worth while to enquire how far ships of any ordinary type are likely to deviate from isochronism, and what specialty of form isochronism implies.

The question requires a comparison between the energy absorbed in the several motions involved in the oscillation of a ship of given form, and the dynamic stability out of the discharge of which the energy is generated in the course of each oscillation.

The statical moment of stability due to the inclination of a given stable floating body, is well known to be wholly expressible in terms of two equal vertical resultants—one, the ship's weight acting downwards through her centre of gravity, and the other, her flotation acting upwards through her centre of buoyancy; their combined action forming "a couple" whose span is the horizontal interval between them.

Thus no horizontal motion can be impressed on the ship's centre of gravity from the statical operation of these forces; nor can any such motion arise in the course of oscillation, except from the secondary or derivative forces involved in the quasi-wave motion impressed on the volumes of water contiguous to the ship, as the result of her oscillations. And as this exception can hardly be serious, and is probably trifling in amount, it remains that practically the whole movement of an oscillating ship may be expressed in terms of an angular motion round her centre of gravity, and a vertical rise

* Received March 27th, 1863.

or fall of the centre of gravity. In the ordinary treatment of the question, the moment of inertia developed under the former condition alone, is regarded as the recipient of the energy supplied by the moment of stability: and the question arises, whether when oscillations of large range are contemplated, enough energy can be absorbed by the latter, to falsify seriously the basis of the ordinary deduction if extended to such oscillations.

This question may be answered in the negative, if the level of centre of gravity statically due to the varying inclination, is regarded as that which it will dynamically assume during the oscillation:* because, as the velocity of descent of the centre of gravity is altogether eliminated at the moment when the half oscillation of the ship is complete, it is clear that whatever energy had been abstracted during the first portion of the half oscillation, must have been rendered back during its latter portion, so that the speed and time lost during the former, must have been pretty nearly reinstated during the latter; and as the velocity of descent is, at its greatest, relatively small, the resulting error cannot be large.

Hence, practically, we may extend to large angles the proposition usually limited to small ones, that the work to be performed in the oscillation of a ship, is measured by her moment of inertia round her centre of gravity.

Hence, Chapman's view, that a ship suspended on a fixed point by her metacentre would oscillate in the same period as if afloat, errs only in the ratio of her radius of gyration when so suspended to her radius of gyration round her centre of gravity, and practically the former would seldom exceed the latter by more than ten or twelve per cent.

If however, the point on which the metacentre hangs be itself free to take lateral motion (as when it is the lower end of a long line suspended from a great height), the oscillation will be performed round the centre of gravity (which will undergo also a small vertical motion), so that the conditions will be almost identical with those of the ship as afloat, and the period of oscillation will be in each case the same.

And if a similar mode of suspension be applied to the plane on which, in a well-known proposition, the ship is supposed to oscillate like a rocking chair, such oscillations, too, will have the same period as those performed by the ship afloat, since here also the disturbing element of horizontal motion will equally be eliminated.

If the form of a ship be such that her metacentre when upright is also her metacentre for all inclinations, she will have the same relation to an isochronous ship, which the ordinary pendulum bears to a cycloidal pendulum; and the enlargement of her periodic

* This condition admits of a lengthened investigation: see a Paper contributed to this volume by Professor Rankine; see also the earlier part of the Paper contributed by me to this volume, respecting Mr. Scott Russell's theory of the rolling of ships.

time when performing an oscillation up to an angle of 50° or 60° (just as when such an oscillation is performed by a simple pendulum), may be sufficiently expressed by a ratio involving a single term of the appropriate series, equivalent to $(1 + \frac{1}{8} \text{ vers } \theta)$; thus, her period when oscillating up to 60° would be only $(1 + \frac{1}{16}) \times$ her period for small angles.

The form of ship which involves isochronism, is that in which the moment of stability is as the angle of inclination; and the question as to what form involves this law, or any other particular law, can only be answered relatively. Given the form of the immersed body, what must be the corresponding form of the superstructure? The strict answer to the question thus relatively stated, can only be given on the supposition that the position of the centre of gravity is defined.

With these limitations, however, it is easy to supply a closely approximate solution, as a corollary to the solution which defines the form of ship which has an unchanging metacentre; and just as it has been shewn that, with a ship of that form, an oscillation of large range differs but slightly in period from one of small range, so it will appear that the introduction of but a small alteration in her form will convert a ship with unchanging metacentre into an isochronous ship.

If we express the immersed body of a ship by an equivalent midship section, the primary type of the form which has an unchanging metacentre is circular; but the same result is secured if throughout all inclinations the immergent and emergent surfaces form the same angle (the one tending inwards, the other outwards, or *vice versâ*) with the line of flotation; and this construction involves the condition that the breadth at the line of flotation (which represents the moment of inertia of the plane of flotation) is the same for all angles.

In this case the ship's moment of stability for any angle of inclination (θ), is given by the usual expression, $\mu = \text{M} \sin \theta$, (M) being the height of the metacentre above the ship's centre of gravity; and the same expression will hold good whether (M) be great or small.

In the isochronous ship the moment may be given by an expression of the same form, only that if the form, $\mu = \text{M} \sin \theta$, be retained, (M) must be regarded no longer as a constant, but as a variable—the variation dating from that limiting value, which it approaches as (θ) becomes small, and when the metacentric intersection assumes the position which, I believe, is sometimes termed the principal metacentre.

It is, however, more convenient to restrict the term (M) to this limiting value: and since in the isochronous ship the term which replaces (M) in the above expression, must have a value growing as the angle of inclination increases, we will call the small excess (ξ), and say, $\mu = (\text{M} + \xi) \sin \theta$, (1); where, on the principle that isochronism

is due to a force which varies directly as the distance from the position of rest (the distance here being an angular distance), we at once obtain the condition, $(M + \xi) \sin \theta = M \theta$, (2). In fact, the isochronous ship differs from other ships only in that she carries out to all inclinations the co-efficient which all ships alike possess for very small inclinations, where $\theta = \sin \theta$, and where the expression, $\mu = M \theta$, or, $\mu = M \sin \theta$, or any other which has the same limiting value, may be indifferently used alike for all.*

Taking our departure then, from the ship which has her metacentre fixed for all values of (θ), let the height of that metacentre above her centre of buoyancy, along her natural vertical axis be called (H), let (M) or the depth of her centre of gravity below the metacentre be called $(m\ H)$, and let the length of the line of flotation in the equivalent midship section = B, which length, as has already been stated, remains constant for all angles of inclination in a ship whose metacentre is fixed for those angles, securing in fact that fixity by remaining constant; where it may be observed, $H = k\ B^3$, k being a constant depending on the displacement, and the position of the centre of buoyancy when the ship is vertical. We have now to deduce from the relation between the forms of immersed body, and of superstructure, which as thus defined establishes fixity of metacentre, such a new relation—such a variation in length of inclined line of flotation—as shall give that rise of metacentric intersection which will satisfy the conditions given in equation (2), and which may now by substitution be transformed into $(m\ k\ B^3 + \xi) \sin \theta = m\ k\ B^3\ \theta$ (3).

Let us then call the inclined line of flotation at each value of (θ), which is required to convert the ship of fixed metacentre into the isochronous ship, (B); and we can add

* I must here refer to a note appended by Mr. Crossland to his Paper on the Rolling of Ships, *Trans. I.N.A.*, Vol. III., p. 14, in which he says, "The true expression for the moment of stability ought to take account of the varying height at "which the vertical, through the centre of buoyancy, intersects the middle line, whereas the expression for the stability "employed in Mr. Froude's investigation, assumes that this vertical always passes through the metacentre. In some ships "the error of taking the angle for the sine may in this way be exactly compensated for."

I trust that what I have here said will remove the misapprehension under which the note I have quoted and the passage in Mr. Crossland's Paper to which it refers, were written.

It is an error to say $\mu = M \sin \theta$, if the ship be of such a form that there is any variation in the height of that intersection.

On the other hand, in saying $\mu = M \theta$, instead of thus committing the double error which I think Mr. Crossland attributes to me, of putting (θ) for $\sin \theta$, without the limitation that (θ) is small, and of assuming the position of the intersection to be always in the metacentre, I was in fact defining a form of ship such that the intersection, instead of being stationary, should travel up the ship's axis according to that precise law which would render her isochronous; or as I have here expressed it in the text, such that she should have $(M + \xi) \sin \theta = M \theta$, a form which, as I remarked, is so simple and ordinary that it may be even regarded as typical.

There is not, therefore, here any error to be corrected in taking the arc for the sine; and in such a case it is a misuse of terms to describe as true only by compensation of errors, a proposition which is in fact integrally true *per se*.

the further condition that whereas the arc of the path of the centre of buoyancy in the former ship is, $s = \mathrm{H}\,\theta = k\,\mathrm{B}^3\,\theta$, ($`s$), the arc of that for the isochronous ship exceeds ($s$) by a quantity which very nearly $= \xi \sin\theta$, as is obvious on an examination of a geometrical representation of the conditions; so that $`s = k\,\mathrm{B}^3\,\theta + \xi \sin\theta$ (4). And further, by the general conditions of fluid equilibrium, it follows that $d\,`s = k\,`\mathrm{B}^3\,d\,\theta$ (5).

The reduction of these questions at once gives $`\mathrm{B} = \mathrm{B}\,(1 + m \text{ vers } \theta)_{\frac{1}{3}}$. Where even up to $\theta = 60°$, no serious error is involved in saying $`\mathrm{B} = \mathrm{B}\,(1 + \frac{m}{3} \text{ vers } \theta)$.

In illustration, it may be added, that (m) is generally about $= \frac{1}{4}$, making $`\mathrm{B} = \mathrm{B}\,(1 + \frac{1}{12} \text{ vers } \theta)$, where if $\theta = 45$, we have $`\mathrm{B} = 1{\cdot}0244\ \mathrm{B}$ very nearly; and if $\mathrm{B} = 60$, $`\mathrm{B}$ becomes 61·46, that is to say, a ship which has a fixed metacentre, whose virtual beam when upright is 60 feet, must to render her isochronous be widened out in her upper works, so that at 45° of inclination the line of flotation is increased by 1·46 feet—a proportion which accords very closely with the old line-of-battle ship type of form.

REMARKS ON THE DIFFERENTIAL WAVE IN A STRATIFIED FLUID.*

By W. Froude, Esq., Assoc. I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 28th, 1863; the Right Hon. Sir J. S. Pakington, Bart., G.C.B., D.C.L., M.P., President, in the Chair.]

This is a curious phenomenon, on which I have stumbled, rather than one at which I have arrived by regular investigation; indeed, the regular investigation seems to present difficulties greater even than those which attach to simple wave motion. I have exhibited in illustration a trough having plate glass sides and a close cover, the trough being filled partly with water, and partly with spirits of turpentine floating on the water, tinted pink to mark the surface of separation. When the liquids are at rest, this surface is of course level; but by a properly managed effort of disturbance, a regularly formed wave can be propagated in either fluid, traversing the surface of separation, and leaving the top surface almost undisturbed. Indeed, it is not necessary that the latter should experience any disturbance whatever, since it is seen that the wave of stratification is then most regularly formed, when the superjacent fluid fills the trough completely, and is in contact throughout with the close-fitting cover.

The velocity of propagation is greatly reduced, as compared with what it would have been had either fluid stood alone; and the reduction should be governed by the difference of the specific gravities, as measuring the operating force, and by their sum, and by the depths of the two strata, as measuring the work to be done.

This relation may be crudely worked out as follows, as it would exist in the double wave of translation exhibited in the experiment:—

If the elevation of a wave of translation be small, as compared with the depth of the channel in which it is propagated, the measure of its velocity is, as Mr. Scott Russell has shewn, $v^2 = g\,h$, (h) being the depth of the channel: and this expression is approximately applicable to negative as well as to positive waves. Were another force, $= n\,g$, to be

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substituted for gravity, we should have $v^2 = n\,g\,h$, or $n\,g = \frac{v^2}{h}$. When, then, the mutual wave is propagated along the meeting surface of the two fluids, as a negative wave in the one and a positive wave in the other, if $({}_1h)$ be the depth or thickness of the subjacent stratum, and $({}_2h)$ that of the upper stratum, the wave travelling with some reduced velocity, say (v), we may infer that the force substituted for gravity in the lower fluid is ${}_1n\,g = \frac{v^2}{{}_1h}$; and that in the upper is ${}_2n\,g = \frac{v^2}{{}_2h}$.

Now each wave travelling independently with this velocity, and actuated by the force thus substituted for gravity, owes its maintenance to its possession of a potential energy, residing in the unbalanced volume of elevation or of depression; and if the form of the wave be given, and the specific gravities be further regarded as variable, the potential energy in each wave will vary in the compound ratio of the specific gravity of the fluid and the force substituted for gravity. Hence if we call the potential energy of each wave ${}_1\mathrm{F}$ and ${}_2\mathrm{F}$, and the specific gravity of each fluid ${}_1s$ and ${}_2s$ respectively, we shall have ${}_1\mathrm{F} = k\,{}_1n\,g\,{}_1s$, and ${}_2\mathrm{F} = k\,{}_2n\,g\,{}_2s$, k being some constant co-efficient to be determined.

Substituting in these values of ${}_1\mathrm{F}$ and ${}_2\mathrm{F}$, the values of ${}_1n\,g$ and ${}_2n\,g$ respectively, we have ${}_1\mathrm{F} = k\,v^2\,\frac{{}_1s}{{}_1h}$, and ${}_2\mathrm{F} = k\,v^2\,\frac{{}_2s}{{}_2h}$.

But ${}_1\mathrm{F}$ and ${}_2\mathrm{F}$ must together make up the sum total of the energy residing in the unbalanced mutually placed volumes of elevation and depression, and will be proportionate to the difference between the specific gravities of the two fluids; and this may be represented by $\mathrm{F} = m\,({}_1s - {}_2s)$, (m) being a constant co-efficient, to be determined.

We may therefore put $\mathrm{F} = {}_1\mathrm{F} + {}_2\mathrm{F}$, or $m\,({}_1s - {}_2s) = k\,v^2\left(\frac{{}_1s}{{}_1h} + \frac{{}_2s}{{}_2h}\right)$. Now, if the specific gravity of the upper fluid, or ${}_2s = o$, the case will be resolved into that of an ordinary wave traversing the lower fluid, and we must have $v^2 = g\,{}_1h$. Hence, it follows that $m = k\,g$, and the expression becomes by substitution $g\,({}_1s - {}_2s) = v^2\left(\frac{{}_1s}{{}_1h} + \frac{{}_2s}{{}_2h}\right)$, or $v^2 = g\,\frac{{}_1h\,{}_2h\,({}_1s - {}_2s)}{{}_1s\,{}_2h + {}_2s\,{}_1h}$.

One characteristic difference between the dynamical condition of the wave surface in an ordinary single fluid wave, and in this wave of stratification, is that, whereas the former is a surface of equal pressure, the pressure here must evidently be unequal; in fact, the pressures and the velocities become discontinuous at the surface of meeting.

This is obvious, if it be borne in mind that the definitely formed wave may exist and be propagated at a velocity reduced to any assignable extent, if the specific gravities of the two fluids be nearly the same. We might thus have the wave with any amount

of inclination of surface, yet moving at so reduced a velocity, and with the velocity of orbital motion of the particles so small, that the general conditions of pressure throughout the volume of fluid, would practically become as near as we pleased hydrostatical instead of hydrodynamical, and that the stratification of equal pressure would consist as nearly as possible of level parallel layers, almost stationary, instead of curvilinear layers having a velocity of undulation exactly corresponding with their curvatures. And this circumstance seems to me to add greatly to the difficulty of a full investigation of the phenomena which such waves exhibit.

The peculiarities of the condition just referred to would run into those which belong to the pressure of a fluid against the surfaces of a body moving through it. And a definite wave of the character under consideration, being a travelling mass or volume of unchanging form, displacing a fluid by pure wave-law as it travels, should be the most correct type of the curve of least resistance.

Some of the phenomena developed are suggestive of possible meteorological conditions, since they show how by a wave-motion once established in atmospheric strata of unequal densities, there may be transmitted a state of disturbance under which contiguous volumes of air are mutually urged in precisely opposite directions, the velocity of translation being greatest at the surface of stratification.

This becomes interestingly apparent during continued experiment. The reiterated agitation undergone by the fluids in the creation of waves, is apt to develope the singular feature of a froth of the lighter fluid hanging downwards into the heavier; and when the trough is slowly tilted and set down again, so as to put in motion part of a very long wave of stratification, the opposite translations of the contiguous surfaces chafing one against the other, roll up the intervening froth into volumes, closely representing the familiar aspect of a mackerel sky.

ON THE ROLLING OF SHIPS AS INFLUENCED BY THEIR FORMS AND BY THE DISPOSITION OF THEIR WEIGHTS.*

By J. Scott Russell, Esq., F.R.S., Vice-President, I.N.A.

[Read at the Fourth Session of the Institution of Naval Architects, March 27th, 1863; the Right Hon. Sir J. S. Pakington, Bart, G.C.B., D.C.L., M.P., President, in the Chair.]

In an admirable Paper, with which our respected Vice-President, Professor Woolley, opened the scientific proceedings of this Institution, he laid before us, with judicial impartiality, the present condition of the science of naval architecture; and he then referred both to the strong and to the weak points of our knowledge, for the purpose of directing our attention, first, to the implicit adoption of the established truths, and their immediate application to our designs of ships, and secondly, to diligent research in those regions of inquiry where sound, if not exact principles were still wanting. Among the points which were well known, and commonly used in professional practice, and which had at least been thoroughly established as matters of science, and clearly stated by men of science, he pointed out the whole of the questions affecting the stability of ships—their power to carry top-weight and pressure of sail in smooth water, and also when in a state of rest. On these, little change can be said to have taken place since the time of Chapman.

Among the points which were unknown to Chapman and the old Constructors, Professor Woolley mentioned the questions relating to the motion of a ship, first, in still water, and secondly, in troubled water. In still water there is the great question of the measure of resistance, or the question of the speed of a ship propelled through still water; and in this we may be said to have solved the most important part by the determination of the form of least resistance, and by its general adoption in the best practice.

The next question, or that of the behaviour of a ship in troubled water, Professor Woolley pointed out as still, to a great degree, unsolved; both in the absence of exact measures, and in the solution of the practical problem,—how to obtain a ship that shall have a minimum of motion, or rather, perhaps, how to obtain a ship of such a nature

* Received April 2nd, 1863.

that the forces of the sea acting upon her shall produce the least possible quantity of these effects which may be inconvenient to her purpose, injurious to her structure, and hindersome to her progress.

I am sure it must be gratifying to Professor Woolley to find that the impulse he gave, and the direction he pointed out, were not thrown away on the members of this Institution. They have already been responded to by three valuable Papers, which adorn the volumes of our *Transactions*. One, full of elegant thought and exact measured investigation, was by Mr. Froude: a second by Mr. Crossland, who grapples with the formidable difficulties of sea-wave motion with a clear insight and a vigorous mechanical discrimination, before which many of these difficulties have disappeared; and in a third Paper, Professor Rankine has offered us a clear discrimination between those phenomena in wave-motion which are the result of gravity acting on disturbed water, and the effects of the revolving motion of the water particles which form the mechanism of propagation of the sea waves.

I have taken to myself in this Paper the investigation of the following narrow question:—What are the forms, proportions, and distribution of weights, which a naval architect would adopt in the present state of our knowledge of this question, as likely to give to a ship the best behaviour in a sea-way, taking into consideration the peculiar circumstances for which the ship may be designed? In the outset of this enquiry we have first to state distinctly the problem,—What is it that you want to find in the behaviour of your ship? Do you want her merely to roll easily and gently? Is what you want, that she shall not fatigue her masts and spars, and rigging? That the sea shall not easily carry anything away? That the sea shall not violently strike anything; and that the hull shall not be damaged, strained, made to work, or, if a wooden ship, be rendered leaky? If ease be the one thing that you want we have only to search for it in a certain direction; and I think we know where to find it.

But we may have to search for qualities very different from these. Easy rolling is good, but there are purposes for which limited rolling, or a small range of roll, is more important than perfect ease. Moderate rolling is above all things what the man-of-war wants. She has a gun platform, the maintenance of which in circumstances fit for action is the purpose and the object of the ship: to maintain this gun platform as nearly level as may be, or as near to a given plane as is practicable, is the problem proposed to the designer of a ship of war, and how to gain this point without losing other good points, and unwittingly getting bad qualities, forms one of his difficult duties. I propose then to seek out from among the various fragments of knowledge which have been contributed to this subject, what are the maxims and recommendations which we may safely adopt, and what are those which we should reject.

There are two problems, therefore, of a very different nature to be solved according to the purpose and use of the ship: that is, according as we wish an easy movement, or a stable platform. But there are certain circumstances common to both, in regard to which it may be well at once to state certain definite conclusions, for which we have ample grounds. Dr. Woolley has himself stated, as the results of the investigations of Bernouilli and others, that the uneasy lifting motion to which many ships are subject, arises from the adoption of injudicious forms near the load water-line. If when the ship rolls on alternate sides the part which goes into the water and the part which comes out simultaneously differ widely in form and bulk, the movements of such a vessel are in a high degree jerky and uneasy. In regard to longitudinal motion, I would beg strongly to call the attention of professional men, as I have done for the last thirty years, to the great inexpediency of those forms of bows which flare out and project violently over the water. It is easy to prove that the flare-out bow has no single advantage except that of giving a fictitious appearance of room on the upper deck; whereas the same room would still remain untouched if the under-water body were extended beyond this bow, so as to render it water-borne instead of overhanging. The flaring bow so long fashionable, and still in use in the inferior sort of clippers, gives to the vessel in pitching an accumulation of vertical motion, and a series of violent concussions with the waves, which are at once causes of great instability of platform, of great resistance to progress, of violent expenditure of power in breaking the waves, and jerky and violent collisions injurious to the strength as well as to the comfort of the ship.

In regard to lateral rolling, Sir William Symonds's earlier vessels illustrated the evils of allowing the midship section of the ship to flare out above the water. By such means great inequality is produced between the ingoing and the outcoming portions of the side of the ship, and the jerking motion is produced which Dr. Woolley has condemned.

The first condition, then, of ease and of moderate motion will be, that the body of the ship shall be so formed, that at the water-line, both on the sides of the ship and all round the bow, there shall be a total absence of flare out above the water, or of rapid falling away under the water. This is to be accomplished by making the surfaces of the ship between wind and water nearly vertical. In conformity with this principle the late School of Naval Architecture, and also their Master, Chapman, made a portion of their midship section nearly vertical; and while agreeing with them to a certain extent, I go a little further and adopt a slightly convex or "tumble-home" line as far as I can, along the middle of the ship; and I approve of as much "tumble-home" at the bow in a large vessel as can be conveniently introduced. In the stern this is less practicable, but it is also less necessary; for there is much less concussion between the waves following in the wake of a ship than in those meeting the bow and striking against it.

I will take for granted, therefore, that all the obviously bad forms have been removed out of the ship, that she does not flare out violently anywhere, that she does not fall away suddenly anywhere, and that all the parts in the neighbourhood of the surface of the water can rise out and go into it again easily, smoothly, and without disturbance. To do this is easy, because, if the vertical sections across do not deviate much from the perpendicular in the region of the water-line, and still further, if they form circular arcs having their centre in or near the plane of the water, all this will take place, and the vessel will roll both ways in the water, without either the jerking or the lifting motion which is the result of a dissymmetry between the parts which go into the water and those which come out.

This preliminary being accomplished, the next question is—What further should we wish to obtain in regard to the movement of a ship on the waves? Do we wish her to rise and fall, and roll and right herself in a lively manner with every undulation of the sea; never taking in water, but, as it is called, swimming like a duck? That is a kind of movement which is very desirable for some purposes. I will call this, for the sake of distinction, the quality of rolling with the sea, and I will carefully examine it.

This rolling with the sea is to be obtained by the simple expedients of great breadth, little draft of water, and extreme lightness with a large and buoyant out-of-water body. I find it very convenient in analysing the properties of a ship to use the phrases, "out-" of-water body," "under-water body," and "shoulders." By under-water body I simply mean the part which in rolling does not come out of the water, and by shoulders I mean those parts which are commonly called wedges of immersion and emersion. I define them to be the parts of a ship between wind and water, and which are comprehended between the planes of the water-line in the extreme rolls of the ship either way; and I call the over-water body that which rises above the shoulders. I comprehend in the shoulders as much as 14 degrees above and below the water, a size which lays a depth of side under the water equal to $\frac{1}{8}$ of the beam of the ship, and which raises a like proportion out of the water.

To use this phrascology, I need only say that to roll with the waves, and be extremely lively, nothing more is necessary than that a ship be all shoulders and over-water body, with very little under-water body. Such a vessel will be able to carry plenty of sail, will be very stiff under canvas, as well as extremely lively: she will take every motion of the sea as if she were a part of it; and she will be a roomy, dry, and comfortable vessel.

I now come to the faults of this vessel. It is obvious that she is not calculated for carrying heavy weights, because she has no depth of under-water body: for passengers

merely, or a light cargo, for small draft of water and for a heavy sea she is safe and lively, but she cannot hold on a wind so as to be weatherly: she is good as a barge, or as a Dutchman, fast to fly before the wind, and wholesome to go on shallow water, end on through breakers and a troubled sea. She is however a barge, a lighter, or a life boat, rather than a ship. The type of this class of vessel may be found on the Dutch coast, at Scheveningen, where they construct the deep-sea fishing boats without a keel; they have a large broad body on the surface of the water, with the beam more than one half the length: all above water, and nothing below. I have seen these vessels come straight on a lee shore through a surf where it seemed to me that nothing could survive; and I may add that although of wood, they are built on the longitudinal system and without frames. For carrying a heavy cargo, therefore, this ship is of no value. She has a specific and great danger: she will roll beautifully excepting in one case.

The great danger of a ship which is all shoulder, and has no under-water body is, that across a sharp and breaking sea she is liable to capsize. When the sea breaks, the front and back of the wave become nearly perpendicular. The shallow vessel which I have described takes of course the position of the surface of the water. Having taken it on the face of the wave, she retains it on the back of the wave, so that what was previously the top becomes afterwards the place of her bottom; in other words, she is turned over. This is the result of extreme liveliness: in all other cases, liveliness seems safety.

This kind of behaviour is the result of rolling with the wave. It may be said to be accomplished in the highest degree by a plank floating on the water: the floating body takes nearly passively the motion and the position of the undulating surface: it is in the water, and is of the water in regard to its rolling; and it may be said that it can roll neither more nor less than the water. The only cause why it can differ at all from the motion of the water is its inflexibility or unfluidity. If it could change its shape as readily as the water, without changing its bulk, it would really be part of the sea.

The condition of this kind of motion is therefore conformity with the movements and the surface of the waves. In smooth water this vessel has extreme stability, in wave water extreme mobility; in smooth water extreme stiffness, and in wave water extreme liveliness.

I will now take a vessel of the other extreme sort. This has been represented by a horizontal plank floating on the surface of the water. The next I shall represent by a vertical plank floating upright, and kept in that position merely by having its centre of gravity slightly below its centre of buoyancy, just enough to maintain it when undisturbed in the vertical position. This vessel also will be part of the water whose

plaee it oeeupies. It, too, therefore, will take the motions of the surrounding water; and it only now remains to eonsider what are the movements to which, in the course of wave motion, it will have to submit. This is a more complieated question than the former one.

It is more complicated because it does not lie on the surfaee. We are familiar with the form which the surface of the water takes in the shape of waves, but we are less familiar with what takes place below the surface. It has required a long series of observations on waves of all sizes, during many years, to sctlle that point. Gerstner, of Berlin, was the first man who, to my knowledge, gave a representation of the theory of these waves, which truly represents the actual phenomena as I have observed them; but on one most important point, namely, the period of the wave, even his examination fails to represent the truth: nevertheless, his view of the mechanism of the wave seems perfectly sound. What happens then, is this:—During every wave, the water not only rises and falls, performing a vertieal oscillation, but it goes backwards and forwards, performing a horizontal oscillation. Its greatest motion forwards is at the top of the wave, its greatest motion backwards is at the bottom of the wave, its greatest motion upwards is at mid-height on the rising wave, and its greatest motion downwards is at mid-height on the descending wave. From this we gather at once, that the floating body standing upright in the water is violently pushed forward during one half of the motion, and backwards, during the other half; and upwards and downwards. And if all the water, down to the bottom of the sea, moved together, one can easily understand how this body might still float upright, even while it was pushed forward and backward, and lifted up and down. Moreover, it is perfectly proved, and admitted, that these motions are performed eireular-wise, and that each point in the water, and each point of this float moves in a circular path, and that their revolutions in this path are perfectly uniform.

Unhappily for the stability of a ship, the circular path in whieh a body floating on the surface moves, and the circular path in which a particle of water, or an immersed body below the surface moves, are very different. If I take a wave of extreme height and go to its depth below the water, I find its motions reduced to little more than a third of what they are at the surface, or to 0·3679. According to the diagram which represents my observations of waves, and Mr. Gerstner's theory, it will be seen that a vertical floating plank is absolutely prevented by incompressibility of the surrounding water from maintaining a vertical position during wave motion; and that it is inclined at a considerable angle from it at all times, except during the instant when it is at the top of the wave, and at the bottom.

The cause of this is, in the first instance, the inequality of the movements of particles near the surfaee and partieles remote from it; and it is worthy of notiee that the

deviation of the vertical plank line from the perpendicular is contrary to the deviation of the horizontal floating plank from the level line or the normal to the curve; and in the case illustrated in the diagram, the inclinations of the one to the right of the vertical line are nearly as great as the inclinations of the other to the left of the vertical line.

We may take, therefore, the two floating planks as types of two contrary kinds of ships, and their movements as types of two contrary kinds of oscillation. Each sort of plank is part of the water, moves with the water, and represents its oscillations.

The practical use to which this contrariety of nature may be applied by the naval architect in the design of a ship may be easily rendered obvious. If he makes his ship all flotation at the surface, it will have the roll of the surface of the wave; but if he combines with the body at the surface a deep vertical body (which might be represented by a vertical plank at right angles to the horizontal plank and connected rigidly with it), it is obvious that it may be so proportioned that the forces acting in the one to produce oscillation one way, may nearly balance the force tending to produce oscillation the other way, and between the two the vessel be saved from rolling. In such a case the body of the ship if weak may be strained, but it will not roll.

Such a ship as I have described is at present all water-line and all gripe; but if I increase the thickness of both planks as I may please, I shall turn the two planks into a practical ship. I shall convert the horizontal plank into good effective shoulders, and the vertical plank into a good sharp bow, a good sharp stern, and either a good flat floor amidships, or a good rising floor, as I think best; and I may so do this as not to impair the tendency of the upper part to remain normal to the water, nor the tendency of the lower part to counteract it. Here is a case where judicious choice of form may be most adroitly made.

It is by following out these views that I have, I believe, succeeded in reconciling together two things hitherto considered the very contrary of each other. I make nearly all my ships without a deep keel on the bottom. I give a broad flat floor, great capacity and stowage room, and great carrying power in the centre of the ship. Such a ship may be readily conceived to have a tendency to roll, and she seems to have little or no gripe. Her circular bilges give most people the idea that she will follow the surface of the water in rolling; but then I counteract the whole of this by the long vertical line of bow, and the very sharp, deep dead wood abaft, with which I form the run of the vessel. Although my vessels are fuller on the surface abaft than other vessels, which tends to give them the motion of the surface, they are much finer below which keeps them from it. Thus then we may obtain by judicious choice of form, that character of vessel which we want amidships for practical use, by giving to the other parts of the vessel where it is not wanted such form as will be an antidote to any bad quality we might anticipate.

The evils then arising from surface oscillation may be remedied by using the peculiarities of deep-water oscillation; and a form that will not follow the surface of the water is effectually provided. It is fortunate that we have such an antidote, for if we could believe that *a large and heavy ship*, in the trough of a sea, whose oscillations were nearly its own, *could be made to add systematically the effects of its own oscillations continually accumulating to the deviations of the undulating surface of the water*, in the manner originally suggested by Bernouilli, and elegantly explained by Mr. Froude, a ship, caught in the trough of a sea by a wave of equal period, must always be hopelessly lost.*

Besides the method I have explained of using the lateral displacements of wavy water to correct the effects of its undulating surface, it is desirable to ascertain how far the disposition of the weights in the interior of a ship can be best made so as to diminish her rolling or give her stability. If, either in the form of the ship or the disposition of her weights, we can prevent the action of the surface from communicating much motion to the ship, and that action from extending over any considerable time, we shall prevent her from readily taking a heavy rolling motion, and from continuing it if it has been caused.

I think we shall all agree in saying that the expression which indicates how we measure the power of a vessel to carry sail in smooth water, may be taken also as the expression of the tendency of surface water when in wave motion to give oscillation to the ship. The height of the metacentre above the centre of gravity of a ship truly measures the leverage by which the weights and bulk of a ship, and the pressure of water on her, enable her to bear up under a press of canvas. It is, in short, the measure of the surplus power which the ship has of standing upright over and above carrying her own top weights.

Now, this same metacentric height measures the power which the water has to set the ship in motion, and also to set in motion all her top weights.

If we call W the weight of the ship, M the height of the metacentre above the centre of gravity, ρ the radius of gyration, and ϕ the inclining force, we have

$$\phi = \frac{W\,M\,\theta}{\rho}, \text{ and } T = \sqrt{\frac{\rho\,\pi}{g\,M}} \text{ time of one swing.}$$

I have no doubt from the investigations, both of Canon Moseley and Mr. Froude, that these two formulæ may be taken truly to represent the moments causing stability, and producing oscillation in still water and measuring the time of an oscillation; and it also seems to me that they are strictly true in regard to small oscillations.

* The *Great Eastern* and the *Warrior* are both examples, showing that the buoyant middle and the fine vertical extremities may unite in neutralising the bad tendencies of both, without injurious action or stress upon the hull of the iron ship. I don't think it could be done equally well in wood.—J. S. R.

But the question I have to discuss here is,—Whether any conclusions we might safely draw from the subject of oscillation of ships, as deduced from these formulæ, could be safely applied to the construction of ships in the actual conditions of a stormy sea? Mr. Froude has ventured to draw from them such conclusions, and to recommend that ships should be constructed so as to have the largest possible periodic time of roll; and he has recommended as the method of giving this long periodic time, the lessening of her stability under canvas. I have carefully examined the subject with reference to the safety of following out such a principle, and I have compared it with the results of a long course of practice of my own, and have come to the conclusion that both in principle and in practice it would be unwise and unsafe to follow this advice.

First, then, I would state, that the formula for the metacentric height does not truly represent the tendencies of a ship to roll in troubled water; next, that a long periodic time of roll is not a certain means of giving a ship easy and safe rolling quality; and thirdly, that a small metacentric interval or height of the metacentre above the centre of gravity may be a great danger.

For the purpose of thoroughly understanding the nature of stability in smooth water, and of instability and danger in wave water, it is necessary to consider carefully, 1st, the true nature of the waves which in a storm cause danger; and 2ndly, to separate from each other the causes of stability and of instability in the ship herself.

First, in regard to waves. I think I am justified in stating as a matter of fact, and of my own observation, that danger to ships does not arise from long, low, and round-headed waves, but from large, high, and sharp-headed ones: that those which cause danger do not occur in even, equal-timed, regular-recurring series, but are exceptionally large and nearly isolated waves; and that those which are dangerous are compound waves in a cross sea.

Secondly, in regard to the ship herself. I have found it most useful to separate in calculation, and always to keep separate in my mind as a constructor, two kinds of stability—stability arising from form, and stability arising from weight—whereas in the ordinary expressions they are confounded; and they have been equally confounded in expressions for rolling. By stability of form I mean the power which is given to a vessel by means of her shape and bulk merely, or by her form and displacement, independently of that which may be given by the centre of gravity or disposition of weights. It is plain that this kind of stability is that which is irrevocably given by the shipbuilder in the lines of his ship; whereas the disposition of the centre of gravity is entirely given by the weights afterwards put into her. It is the first which determines the character of the vessel, and it is, therefore, the most important.

In order to understand the nature of stability of form apart from that of weight, we must place the centre of gravity where it can have no action on stability; and for this purpose place it in the axis of motion, or in the centre of the water-line of such a ship as I am about to describe. Suppose the ship to be inclined by any couple of forces, we have the part under water divided into two, a symmetrical body, and an unsymmetrical one—the symmetrical part always under water, the unsymmetrical placed under water or taken out of it, as the ship inclines to either side: the one, for convenience sake, I call the shoulder, and the other the under-water body. In reference to stability these bodies have opposite functions: one exercises righting power, and tends to upright the ship, while the other exercises upsetting power, and tends to overturn her. The resultant of these two forces determines the stability or instability of the ship. The distance of that resultant from the middle, or the momentum of that resultant force measures her power to resist overturning, whether that overturning shall be force of sail, top weight, or any other force. The distance of this resultant from the axis of the ship, is one measure of her stability, because it would sustain her whole weight shifted much to one side; or it would sustain a top weight equal to the whole weight of the ship lifted as high as where this point intersects the vertical line.

To translate this into the ordinary expression of stability is merely to say that in this case the height of the metacentre above the water-line measures the stability of the ship arising from form and bulk merely, or what I have called stability of form; and I think it very important to observe that this height measures the quantity of forces called into action either for stability in still water or instability in troubled water, and that these forces truly represent the action of the water on the body independent altogether of any action of weight whether these forces tend to produce motion, or to resist pressure.

I now pass to that kind of stability and of instability which arises from weight. For this purpose I remove the centre of gravity out of the axis of rotation where I had put it, and I will first raise it above so as to get the action of top weight. There, as top weight, it tends to overturn the ship. In doing so it counteracts the righting power of the shoulder, it conspires with the upsetting power of the bottom, it tends to overturn the ship, and it diminishes the power of carrying canvas. In proportion as I raise the weight, I counteract the stability arising from form; and, at last, when I reach the height of the metacentre I have neutralised by an opposing force the whole of the stability arising from form.

It will not be impertinent here to make apparently an axiomatic observation. The stability of form remains as great as ever, even when I have neutralized its effects, or rather worked them up by raising the centre of gravity, or by accumulating top weight. The ship has still great stability of form, and the forces producing it are doing great

work; they are supporting heavy top weight, although the ship has in one sense no stability inasmuch as she could carry no sail, and as any further top weight would overturn her; yet she has great stability of form. But this stability is fully tasked, and is doing its utmost.

There is surely great difference between a ship doing enormous work, and able to do it, and one doing no work, and unable to do any; nevertheless, this ship has now in that sense no stability if we fail to distinguish between the stability of form and that of weight.

To discriminate between these cases for the future, we must be more careful in the use and application of the word stability: what we call a measure of stability is more properly a measure of spare or surplus stability, or stability still to be disposed of. I would call the measure of stability of form of a ship, the absolute height of the metacentre above the water-line, the height of the centre of weight above the water-line; or the height of the centre of top weight would be measured by the height of the centre of gravity above the same line, and the remaining height left between the centre of gravity and the metacentre would be the just measure of the surplus or remaining power of stability still remaining to be disposed of. This height of the metacentre above the centre of weight is the ordinary representative for the stability of the ship. It is the true representative of the surplus merely.

I will now shew the errors into which this confusion of terms and the consequent confusion of thought, have a tendency to lead us, and may have led some of us. We talk of the distance between the metacentre of a ship and its centre of gravity as if this line were a quality of the shape of the ship, and the centre of gravity a quality of the ship herself, instead of the mere result of stowage and trim. The consequence of this error is that two ships which have this line of the same length, say 6 feet, are taken as identical ships as far as their practical uses and behaviour are concerned; and therefore, it has been said, and may be imagined that you have only to give half a dozen different ships the same metacentric height, and they will have the identical behaviour.

What is true is merely this,—that force is proportioned to the masses moved, and that forces of small amount will move the ship through small axes in equal times—a statement, *cæteris paribus* quite true; but not of the practical value which may be, or has been attached to it.

I now proceed to call attention to the circumstances under which vessels having the same interval of distance between the metacentre and the centre of gravity will have a totally different behaviour in sea-way. For this purpose I take a vessel possessing great stability of form loaded with great top weight. In the case of such a vessel

placed on the slope, the over-turning force may consist, not of the difference between the metacentric force above the axis, and that of the centre of gravity, but of their sum.

I will next take the case of a vessel placed suddenly on the crest of a sharp wave. This may result not from a large single wave, but from the coincidence of two moderate waves. In passing suddenly from one of these positions to the other the ship acquires much momentum, and the weight of the ship acts to prolong a dangerous oscillation. The metacentric force is an overturning force, and the force of gravity is also overturning.

From my own investigations, fortified by my own observations and experience, I should adopt very different maxims from those which Mr. Froude thinks warranted by his views and investigations.

1. I should not regard it as expedient to design a ship with a high metacentric height out of the water attended by a high centre of gravity, for the purpose of diminishing the velocity of oscillation:

2. I should not design a vessel with weights placed high for such a purpose, nor with weights placed at a great distance from the axis of revolution for the same purpose:

3. I should endeavour to diminish the violence and the extent of rolling motion in the design of a new ship, by diminishing the total metacentric height above the axis of rotation or the water-line. I should by this means seek to diminish the forces by which the water acts to cause rolling in a ship:

4. The extent to which the absolute metacentric height may be reduced in a good form of ship is great. There is no difficulty in reducing it even to the level of the water at the load water-line if it were desired; and,

5. The extent to which the place of the centre of weight of the ship and cargo may be lowered easily must depend mainly upon the use and purpose of the ship. But with a low place of metacentre and a lower place of centre of gravity, possessing only the interval between them required for carrying sail, all the injurious movements and injurious stripes, which strain, or injure, or endanger a ship will be a minimum; and all the forces tending to produce oscillation being reduced to a mimimum in total quantity, we shall have the least wave of strength and force.

Figs. 1, 2, and 3 of Plate X, exhibit the mechanism of sea waves, as described in my Paper published in the *Transactions of the British Association* for 1844. Fig. 1 exhibits the highest possible wave before breaking. Fig. 2 is a lower wave. Fig. 3 one still lower. The outlines of these waves are all cycloidal, the highest only is a pure cycloid. The construction of this wave as shewn in this plate is as follows:—Each particle of water during the wave motion makes a complete revolution in a circular order with a uniform motion, the period of which is the time in which the wave travels

through its own length. The uniform motion of each particle in its circular orbit, combined with the uniform motion of the wave horizontally, produce the cycloidal curves which divide the successive layers of the water from each other. The layers of water which are level in repose become cycloidal in motion. The diameters of the circles in Fig. 1 shew the rapid diminution of the circular movement as we go below the surface, while the horizontal movement of the wave remains uniform through the whole agitated depth. The shaded areas in Fig. 1 shew the different forms which given portions of the water take in different parts of the waves. These forms are all rectangular parallelograms when the water is still, and each of the shaded masses changes its place, as well as its form during every successive part of one wave period.

It is one of the beautiful characteristics of water in wave motion, that uniform circular motion and uniform horizontal movement take place together in every particle of the water, while, successively, all particles on the same level line, when it rests, go through precisely the same movements one after the other. To reconcile these motions with one another is mere geometry; to reconcile them with the continuity of the fluid is a higher mathematical problem, and to shew how the force of gravity acting on each particle of the water, combined with a revolving force which has been given to that particle, shall successively propagate, and continue the wave motion from one part of the fluid to another, is to solve the difficult problem of wave mechanics.

Fig. 10 shews the successive positions which a thin deep body floating vertically in water, when it rests, will successively take during the period of a wave of the form of Fig. 2. Fig. 11 shews the successive positions which a broad shallow body floating horizontally in water, when it rests, will successively take during the period of a wave of the form of Fig. 2. The same forms are again shewn as they appear on the surface of the wave in Figs. 4 and 5, Fig. 4 corresponding to Fig. 11, and Fig. 5 to Fig. 10. In Fig. 6, a compound body is shewn partly thin and deep and partly broad and flat, a form which always floats in same position, somewhere intermediate between the two, varying as either of the two forces happens to be the greater.

Fig. 7 shews a form of vessel which like the Scheveningen boat follows implicitly the form of the surface. Figs. 8 and 9 shew forms of vessel in which the vessel is prevented from remaining comformable to the surface by the action of the water on the under-water body in comformity with the vertical divisions of the fluid.

In all the figures, the numbers 1, 2, 3, 4, 5, 6, 7, represent successive instants of time, and successive places of particles.

REMARKS ON MR. SCOTT RUSSELL'S PAPER ON ROLLING.*

By W. Froude, Esq., Assoc. I.N.A.

Bearing in mind Mr. Scott Russell's varied and extended experience as a shipbuilder, as well as the mathematical skill, and the general scientific knowledge which he has from the first devoted to the pursuit of naval architecture, it is natural that I should feel some diffidence in maintaining views differing it seems fundamentally from those in which he embodies the result of his experience and his investigations, in relation to this important part of his professional knowledge. Yet under the circumstances I am bound to trace the points of difference, not controversially indeed, yet as distinctly as possible.

The difference is now perhaps least marked in words, yet scarcely less real, where Mr. Scott Russell, following Dr. Woolley, lays great stress on a conclusion enforced by Chapman, that when the form of a ship is such that in heeling, the emergent solid differs widely in bulk and form from the immergent, her rolling must be in a high degree jerky and uneasy, in consequence of the rising and falling motion in the axis of the plane of flotation, which must accompany her oscillation.

On this point I should have been content, when Mr. Scott Russell's Paper was read, to recur to the remarks of mine, bearing on the point, which appear in Vol. III. of the *Transactions*, (foot note to page 38,) in which I stated confidently that, since an extravagant (imaginary) Symondite ship, say of 60 feet beam, rolling to an angle of 20° off the perpendicular, would only experience a rise of 8 or 9 inches in the axis of her plane

* The very imperfect character of the remarks which were the best I could offer on the spur of the moment, after the reading of Mr. Scott Russell's Paper, coupled with the importance of the subject, will, I trust, be considered a sufficient justification of the permission which has been accorded to me to embody in a substantive Paper, for insertion in this present volume of *Transactions*, all that on mature reflection I could feel I had to say respecting it.

Knowing my views to be extremely at variance with his own on some fundamental points, Mr. Scott Russell has, nevertheless, himself kindly put me in possession of the proof sheets of his Paper, in order to facilitate and render more directly applicable what in a certain sense must be called my reply: and I cannot but regard this as a conclusive evidence that he desires simply the fullest elucidation of the subject, excluding entirely those controversial modes of thought which are very apt to intrude themselves into the discussion even of purely scientific questions.

I cannot better express the value I place on this non-controversial mode of treating the subject than by shaping all I have to say in exact harmony with it.

of flotation, the cause appealed to was manifestly inadequate to the alleged effect; the more so, as meanwhile, the ship's sides would be oscillating through more than 20 feet, and the ship herself would be probably rising and falling many feet with the waves; so that the special kind of rise and fall of centre of gravity under consideration must be, by comparison, insignificant, and must be merged in the larger motions with which it would be interwoven. This statement, however, now requires qualification.

I had indeed long been aware that the peculiar rise and fall which we are considering, when it involves the rise and fall of the ship's centre of gravity, may tend to set up a subsidiary series of vertical oscillations. For the fact that the centre of gravity has undergone a bodily elevation (however small) implies that it must have been urged by an upward accelerating force; and this force must have been supplied by an excess of support due to a depression of the plane of flotation below its level of statical equilibrium. Again the descent of the centre of gravity, in turn implies that the mass has experienced a downward accelerating force, such as can only have been supplied by a want of support, due to an elevation of the plane of flotation above its level of statical support.

That such an alternate elevation and depression in fact constitutes a species of oscillation, and that this might possibly be amenable to regular investigation, is sufficiently obvious. But the circumstance had not appeared to me to demand investigation; not only on account of its apparent difficulty, but because it seemed on the one hand, that the forces in which the oscillation originates, must, in any practically assumable case, be in themselves small; and on the other, that since obviously such a floating body as a ship would perform, in still water, its vertical oscillations in a much shorter period than its transverse oscillations, there could be little danger of that accumulation of effect which has been shewn to arise, when a derivative oscillation naturally synchronizes with that recurring impulse from which it is derived.

On learning however that Professor Rankine had sent to the Institution a Paper (which will be printed in this present volume of *Transactions*) in which among other objects of enquiry, the particular case of oscillation to which I am referring is investigated, I became convinced that its importance must be greater than I had supposed: I have therefore since then, endeavoured with tolerable success, to obtain an availably approximate solution, and I have arrived at results which fully verify the conviction.

As the question is in the hands of Professor Rankine, whose investigation is, I doubt not, far more complete than my own, I will not occupy the pages of this volume with the details of my own. I will, however, slightly sketch its course and its results.

I succeeded in obtaining a differential equation of motion, expressing the elements of these vertical oscillations of a ship, in terms of the elements of her co-existent transverse oscillations, supposing these to be artificially maintained in still water. The equation is extremely analogous to that from which, as given in my Paper, in Vol. II. of the *Transactions*, I deduced an expression for a ship's transverse oscillations when rolling in a sea-way. It is integrated by a similar artifice, and its results are also closely analogous; though there appears in their most critical feature a singular point of contrast which was to me unexpected, but which is perfectly intelligible when it is duly examined.

In that former investigation, it may be recollected that (T) stood for the period in which the ship will complete an oscillation in still water from starboard to port, or *vice versâ*, and (T′) for that in which a wave travels its own length from hollow to crest; and the critical feature of the result was, that among the various phases of recurring oscillations which it expressed, the details were governed by the ratio $\frac{T}{T'}$, in such a way that the maximum oscillation in each complete phase became greater in proportion as the ratio $\frac{T}{T'}$ approached unity.

In this latter investigation, retaining (T) to represent the period of a transverse oscillation in still water, and putting (τ) to represent the period in which the ship will complete a vertical oscillation in still water from the highest to the lowest point, or *vice versâ*, an equation is obtained which expresses a very similar series of phases, the details of which are analogously governed by the ratio $\frac{\tau}{T}$; but here in such a way that the maximum in each complete phase is greater as the ratio $\frac{\tau}{T}$ approaches, not unity, but $(\frac{1}{2})$.

The complete equation represents the maintenance of any previously impressed vertical oscillation, as existing concurrently with those vertical oscillations which are derived from the ship's transverse oscillations; the two series each maintaining its independent and complete vitality, just as happened in the equation of rolling motion.

I give here, for shortness, the terms which express the derivative oscillations alone:—

$$h = \frac{r\,\Theta^2}{4}\left\{\frac{1}{1-4\,\frac{\tau^2}{T^2}}\left(\cos\frac{2\,\pi\,t}{T} - \cos\frac{\pi\,t}{\tau}\right) + 1 - \cos\frac{\pi\,t}{\tau}\right\},$$

Where (h) stands for the elevation of the centre of gravity, in the vertical oscillation, above its level of undisturbed flotation in still water; (Θ) for the arc of the extreme angle or range of the transverse oscillation from which the vertical oscillation is derived;

(r) for the vertical distance between the ship's centre of gravity, and that point in her vertical axis from which, as centre, the circle must be described which most nearly osculates, or is coincident with, the figure of the ship's equivalent midship section, at and near the water-line, when she is upright in still water; τ and T for the periods of vertical and transverse still-water oscillation respectively, as already described.

When the ratio $\frac{\tau}{T}$ assumes the value $\frac{1}{2}$, the equation becomes—

$$h = \frac{r\,\Theta^2}{4}\left\{1 - \cos\frac{2\,\pi\,t}{T} + \frac{\pi\,t}{T}\sin\frac{2\,\pi\,t}{T}\right\}.$$

I have some reason to believe that, in such ships as are called "Symondite," the period of a complete vertical oscillation in still water, is not far from $\frac{1}{2}$ of that of a transverse oscillation. Now, the imaginary extravagant Symondite referred to just now would have an equivalent midship section of such a form, that a circle of contact, embracing her sides near the water-line, would be struck from a point in her axis, about 10 feet above the plane of flotation, making $(r) = 10$. And if we were to assign to her the exact ratio above referred to, $\left(\frac{\tau}{T} = \frac{1}{2}\right)$, and to assume that she maintained her transverse oscillations to a range of about 22° (making $\Theta = 0{\cdot}4$), her derived vertical oscillations would be described by the equation—

$$h = 0{\cdot}4\left\{1 - \cos\frac{2\,\pi\,t}{T} + \frac{\pi\,t}{T}\sin\frac{2\,\pi\,t}{T}\right\};$$

and if we cut up the periods of the successive transverse oscillations into four equal parts, making (t) run through the successive values $\frac{T}{4}$, $2\frac{T}{4}$, $3\frac{T}{4}$, $4\frac{T}{4}$, &c., then, in the first period (T) thus completed, the variable part of the equation will assume the successive values $\left(1 - \frac{\pi}{4}\right)$, $(1 + 1)$, $\left(1 + \frac{3\,\pi}{4}\right)$, $(1 - 1)$; and in the subsequent periods (T) thus completed, the first of these terms will run through the successive values $\left(1 - \frac{5\,\pi}{4}\right)$, $\left(1 - \frac{9\,\pi}{4}\right)$, $\left(1 - \frac{13\,\pi}{4}\right)$, &c.; the second of the terms will be always $(1 + 1) = 2$; the third will run through the successive values $\left(1 + \frac{7\,\pi}{4}\right)$, $\left(1 + \frac{11\,\pi}{4}\right)$, $\left(1 + \frac{15\,\pi}{4}\right)$, &c.; the fourth will be always $(1 - 1) = 0$, &c.

Hence, in the series of vertical oscillations, the range, beginning with zero, will, for each completed half transverse oscillation, have a definite unchanging value, and will return to zero at the completion of the whole transverse oscillation; but at the first quarter of each transverse oscillation there will be a constant addition to the depression; at each third quarter a constant addition to the elevation; and completing the numerical translation, as it affects the imaginary ship, her centre of gravity will, at the successive

assumed periods, experience the successive elevations (expressed in feet), 0·00, + 0·087, + 0·800 (*N.B.*—this is also the elevation which it would statically assume were she held by a couple, at the corresponding inclination) + 1·14, 0·00; − 1·17, + 0·80, + 2·60, 0·00; − 2·44, + 0·80, + 3·82, 0·00: and so forward. In fact if the transverse oscillations were maintained with unabated range, the vertical ones would continue to increase in range by equal steps, oscillation by oscillation, were not the accumulation limited by the growing resistance of the water, which must be developed with greater and greater intensity as the velocity of motion increases.

The resistance of the water may in fact be regarded as supplying the chief practical limit to the progress of accumulation under the assumed condition; since though as the range of vertical motion becomes greater and greater, the approximations on which the equation rests will depart more and more widely from the real conditions, the resistance will be found already to have imposed its limit on the range, before the departure has become very material. I will therefore indicate the scale and character of the limitation which may be expected thus to arise, by tracing approximately its development, as it would arise in the case of the imaginary "Symondite" under the circumstances already assumed.

During each derived vertical oscillation, there is, under these circumstances, a fixed amount of cumulative energy supplied by the primary transverse oscillation—the same for each oscillation. And this is precisely measured by the increased energy which would be stored up in each successive oscillation, were the oscillations performed without resistance, and were the accumulation to ensue by the steps already stated.

On the other hand there is absorbed during each of the vertical oscillations, a certain amount of energy or work, expended in overcoming the resistance of the water. And this becomes greater and greater, as the range (and therefore the velocity) of the oscillations increases, until its amount equals that of the fixed increment of energy supplied during each oscillation.

The resistance of the water, acting on the ship's body as she rises and falls, will vary pretty nearly as the square of the velocity of her vertical motion; and since the oscillation is nearly, and may be regarded as, isochronous, this velocity will be for each oscillation, as its range. We must next find some proper co-efficient.

Now, the resistance to a plane moving orthographically through water, with a velocity of 10 feet per second is about 100 lbs. per square foot. Again, at that speed the resistance of a full-bowed frigate, is about 18 lbs. per square foot of midship section.

It therefore seems to me that we may assume as probable that to a ship rising and falling alternately with that velocity, the resistance will not fall short of 30 lbs.

per square foot of plane of flotation, and might possibly be much more than that; especially if we take account of the circumstance, that each oscillation must set in motion a current which acts obstructively on that which follows—a circumstance which is strongly marked in experiments relating to oscillations in a resisting medium.

I therefore adopt, as sufficient for the present illustration, the expression, resistance $= 0{\cdot}3\ V^2$ as the measure of the resistance per square foot of plane of flotation.

Now, if a series of isochronous oscillations be laid down as a diagram, exhibiting "range" as ordinate, and "time" as abscissa, its features adhere to the type of the curve of sines; according to which the maximum velocity $= \left(\frac{\pi}{2}$ or $1{\cdot}57\right) \times$ the mean velocity, measuring this by the total range and the corresponding period; and as the maximum velocity is continued with very little abatement through a large portion of the whole range, the working velocity throughout the space traversed may be treated as $1{\cdot}3 \times$ the mean velocity.

In our assumed case, the period of a single vertical oscillation is 2″, and if s $(= 2\,h)$ be its range from out to out, the velocity in feet per second, $V = \frac{1{\cdot}3}{2} s$; hence during any given oscillation, the mean resistance throughout its space, or $R = 0{\cdot}3\ V^2 = 0{\cdot}3 \times (0{\cdot}65\ s)^2$. Again, the work done, or energy absorbed per square foot in overcoming this resistance, is, $E = R\,s = 0{\cdot}1265 \times s^3$; and this must be applied to the area of the plane of flotation, which we will call (A) and which would be about 10,800 feet.

Thus the whole energy absorbed, reduced to "foot tons," will be $E = \frac{10800}{2240} \times 0{\cdot}1265\ s^3 = 0{\cdot}612\ s^3$.

The corresponding increment of energy supplied, may be measured by the weight of the ship, and the increment of vertical range which would arise, or the additional height to which she would be lifted during the oscillation, if no resistance were experienced. And this increment of range, as may be seen by reference to the tabular statement, is 1·25 feet in a double, or 0·625 in a single oscillation. The force employed in lifting the ship at any mean height of lift $\left(h$ or $\frac{s}{2}\right)$ is $= \frac{A}{35} \times \frac{s}{2}$ tons; and this, acting through 0·625 feet, gives E′, the energy supplied, $= 96{\cdot}4\ s$ foot tons.

Hence accumulation will cease when $E = E'$ or $s^3 = \frac{96{\cdot}4\ s}{0{\cdot}612} = 157{\cdot}4\ s$ and $s = 12{\cdot}55$. That is to say, if the assumed ship be obliged to continue her transverse oscillation with a constant range of 22°, she may be expected to arrive at a state of vertical oscillation, in which she is alternately just 6·3 feet above, and 6·3 feet below her mean level of flotation.

If we put the conditions on which the limitation depends into their ultimate form in mathematical language, it stands

$$s = \sqrt{\frac{r\,\pi}{m}} \times \frac{T\,\Theta}{1{\cdot}3},$$

Where (the reader may be reminded) (s) is the range of the greatest possible vertical oscillation from out to out; (m) is the co-efficient of resistance per square foot of midship section in the expression, resistance $= m\ V^2$; (r) is the vertical distance between the ship's centre of gravity and that point in her vertical axis whence a circle may be described most nearly embracing her sides near the water-line; (T) her period of transverse oscillation; and Θ the extreme range of the constantly maintained transverse oscillation from which the vertical oscillation is derived.* The result is independent of the plane of flotation.

These conclusions to which I have been led by the principle pointed out by Professor Rankine appear to me in themselves interesting and important, and will I hope prove to be in general conformity with those which he has himself deduced from it.

So far as the reputed uneasiness of ships of the "Symondite" type may be regarded as evincing the fact that very extensive vertical oscillations are more or less frequently

* It might have been expected (at least, I myself certainly expected to find) that in all such derivative oscillations, the tendency to unlimited accumulation would be developed, not only when the periodic times of the primary and the derived oscillations so harmonized as that each impulse supplied by the former should fall with exact concurrence (*toties quoties*) on the motions of the latter, but also when the ratio between the periods was such a whole number that though during the lapse of the larger of the two periods, there might be included several retarding, as well as several accelerating impulses, the latter should be in excess of the former, and that this excess should be repeated identically as often as that period was repeated. And this remark applies equally to the analogous case of transverse oscillations derived from recurring wave impulses.

But no such result follows in either case from the equations which express the appropriate law of the derivative motions, or rather, the equations in each case distinctly negative the possibility of the expected result. For if we substitute in them respectively for the ratio of the periodic times, any whole number but that which evolves the special accumulation already discussed, *viz.*, $T = T'$ for the case of a ship rolling in a sea-way, and $\tau = \frac{T}{2}$ for the case of a ship performing vertical oscillations derived from transverse ones in still water, we obtain from each simply a series of identically recurring phases, each phase comprising a number of successive oscillations, growing up to a *maximum* and dying out again by like degrees; the *maximum* range in each case being smaller, in proportion as the ratio of the periods differs more widely from the special ratio which evolves the condition of perpetual accumulation.

In fact, no such ratio can be assigned as shall practically secure a preponderance of accelerating impulses in each successive phase, since the period in which the derived oscillations are actually performed, becomes so modified by the periods at which the impulses recur, that the *maximum* derived oscillation inevitably occurs in the centre of the phase; which thus always contains as many retarding as accelerating impulses, so that, phase by phase, there can be no increase in the *maximum*. Viewed in this light, the individual oscillations in the series of continued accumulation, are to be regarded, not as being each a phase complete in itself, but as forming the successive steps in an interminable phase, the completion of which would involve an infinite number of such steps; of which however the concluding terms are not less possible than the commencing ones, and would recur as regularly were the ship started with an oscillation under conditions exactly conforming to one of those steps, and timed into its due relation to the recurrence of the impulse.

experienced in such ships, the principle furnishes a scientific justification of their ill repute, by legitimately explaining how such oscillations may arise from their peculiarity of form.

I do not, however, the less think that prior to Professor Rankine's exposition, the dictum alleging the necessity of the uneasiness, was destitute of scientific justification. It was then held by the highest authorities* that the vertical motion to be taken account of was practically limited to that statically due to the ship's inclination; and I believe that while concurring in that view, I was entitled to assert that as the motion itself was so insignificant, the uneasiness directly resulting from it must be insignificant also.

But the new light which has been thrown on the question shews that under certain conditions the grounds of the assertion fail; and the assertion itself has to be reconsidered and suitably remodelled.

At least, were I myself, whether in a ship or elsewhere, to experience a reiterated alternate rise and fall of 13 feet, each double movement being performed in each successive interval of four seconds, I should be obliged to admit in words that the motions were "in a high degree jerky and uneasy," or I should probably be speedily convicted of error out of my own mouth.

But mere physical uneasiness is not, I believe, the point chiefly contemplated in the dictum, and it is worth while to enquire what degree of mechanical uneasiness (stress on the ship's frame or cargo) may be expected to arise under the circumstances.

The real question is, what forces or stresses do such motions develope, and bring to bear on the masses of matter in which they are developed, and how will these masses be affected or strained in consequence?

The primary and most simple mode of representing the force developed on a mass so circumstanced is, by saying that the natural gravitating force of the mass is virtually increased or diminished in a given ratio, the ratio being determined by a comparison of the actual accelerations experienced, and the well-known term (g); and though the subject deserves and probably has received a much fuller investigation than I can give it here, I shall add some few remarks bearing on it, in order to adapt the views expressed by me, as recorded in the last volume of our *Transactions*, to that improved perception of the amount of vertical oscillation, which on examination, it seems, ships of the Symondite type may become subject to under possible circumstances, and which I have by a rough approximation measured.

* See Dr. Woolley's Paper, *Trans. I.N.A.*, Vol. I., pp. 23, 24, where attention is drawn to Canon Moseley's observation, that when a ship is rolling, "there cannot but result small vertical oscillations independent of the principal oscillation," coupled with an expressed belief that the error involved in the disregard of these would probably be by comparison small.

It appears to me, then, that a mere alternate increase and diminution of the virtual force of gravity, as affecting the parts of an adequately supported structure, tends to produce no real distress in the structure, so long as, on the one hand, the increased force does not exceed that which is usually amply provided for in the margin of strength supplied; and so long as, on the other hand, the decrease does not in any way develope an actual force in the opposite direction. The same variation of load, which might be fatally injurious if it were to produce actual alternations in the direction in which the resultant force operated, might safely be regarded as quite harmless, so long as the pressure continued entirely in one direction, though the absolute magnitude of the maximum stress were much greater in the latter case than in the former.

Now, of the forces experienced by a ship in rolling, those which are developed by the acceleration and retardation of angular motion all distinctly involve alternations, not only in the intensity of the forces which support the various parts of the structure and of the cargo, or other detached weights, but also in their direction: the strains developed are essentially racking strains. Not only do the guns and other outlying weights press alternately with more or less force on their supports (and this in no inconsiderable degree when the range of motion is taken into account), but all the weights throughout are alternately swayed from side to side, tending to "fetch way," and pulling by jerks on the supports which restrain them. Again the "moments of stability," pressing on the hull in alternate directions as the ship rolls from side to side, develope alternating stresses of distortion, producing especially in timber ships, a visible amount of "working."*

On the other hand, the oscillations which involve vertical motion only (unless so rapid as to develope a force greater than gravity), produce, primarily, no racking strain. Thus, were the imaginary illustrative experiments tried, which I suggested in my Paper, *Trans. I.N.A.*, Vol. II., p. 194; that is to say, were a bucket full of water, and containing a floating body, placed on the end of the piston rod of a vertical reciprocating engine, we should have a pure and correct representation of such oscillations: where, though the variation of the pressure which the fluid and the body would mutually exert against

* This may be interestingly noticed in the behaviour of a transverse cabin bulkhead, when, as is frequently the case, it is papered. At each roll of the ship a series of oblique creases is developed in the paper, where it crosses the upright joints of the boarding, the direction of the obliquity becoming alternately right-handed and left-handed as the direction of the force changes, witnessing thus to the fact that the bulkhead frame is being alternately forced out of square in alternate directions. A similar evidence of distortion is given by the deck seams at the waterways, where, when the ship "works" in heavy rolling, the deck beams serve as levers by which the seams are alternately opened and closed, the knee fastenings which secure the beam ends to the ship's sides, and which lie chiefly in the plane of the lower surface of the beams, supplying the fulcrum from which the lever in each case acts, as her change of form under the alternating stress renders the angle at the fastening alternately more acute or less acute.

each other, and which the weights carried by the body would exert against their supports, are readily understood, it is, I think, obvious that no stress of a trying character would be developed.

The rise and fall of a ship as the waves pass under her, is very closely analogous to that just described: if, at least, we assume that each wave acts simultaneously on her whole length; and if we distinguish the vertical component of motion from the component due to that transverse oscillation by which the vertical oscillation would, under the circumstances, be more or less necessarily accompanied: and it is plain, I think, that here also no trying stress is developed.*

Closely analogous again to this vertical oscillation of a ship rising and falling on the waves, is that special kind of derivative vertical oscillation which it has been attempted to trace—only that here, the co-existence of transverse oscillation is an essential, while in the other case it was only an accidental, or a possible collateral condition; and in tracing the forces which the successive vertical oscillations impress on any point in the ship, we must take account of the forces which the co-existent transverse oscillation (regarded as an angular motion round the ship's centre of gravity separately) would impress on the same point.

In fact, we may take account of the whole oscillating force which is impressed on any given point in the midship cross section of the ship, when oscillating in a sea-way, if we take account (1) of the purely vertical oscillations due to the rise and fall of the waves, which will affect all points in the section alike; (2) of the transverse oscillations which the wave motion generates in the ship, and which I am satisfied are governed substantially by the conditions, to which, in former contributions to the *Transactions*, I have attributed them (though I have yet to maintain that point as against Mr. Scott Russell's present Paper); and (3) of the vertical oscillations derived from the transverse—the laws of which I have been (somewhat crudely) tracing in this Paper.

In proceeding to sum up this account, on the principles now explained, it is material to notice that the actual periods at which each phase of each of the three oscillations comes into existence, are connected by a distinct law with the simultaneous condition of the others. Thus we may conceive such a transverse oscillation as we have supposed, to be maintained by the transit of a series of waves having a period identical with the ship's period, and of due dimension. In this case the instant of maximum range in transverse oscillation occurs when the ship is alternately engaged with the highest point of the

* The trying stress primarily developed by wave transit, consists of the "cantilever" strains which the unequal distribution of support along the ship's length creates in the longitudinal structure of the hull, and which under the changeful phases of the inequality subject both the bottom and the upper works to a reiterated alternation of tension and compression.

wave crest, and with the lowest point of the wave hollow.* On the other hand, on comparing the periodic condition of the transverse oscillation with that of the vertical oscillation which is derived from it, it appears that the instant of maximum vertical elevation or depression, in the latter, occurs exactly at the mid-period of each half transverse oscillation, and when the period of maximum range in each has either not been quite reached or is just passed.

Bearing these conditions in mind, let us see what is the maximum force, or variation in force, which can be impressed on any point in the midship section of our imaginary Symondite, under the combination of the conditions whose separate effect on her has already been partially traced; and to complete the data, we must first assume suitable dimensions for the waves by which the oscillation is maintained.

These must have the same period as the ship has, *i.e.*, (4″) for the time of transit from hollow to crest; a period corresponding with a length of 160 feet and (let us say) a height of 16 feet, from hollow to crest, the mean height being therefore 8 feet. †

We shall have determined the maximum vertical force impressed on any point in the hull, if we refer to the extreme surface of her midship bend, where the transverse oscillation brings the greatest addition to the effects of the purely vertical oscillation.

Here the 22° of range, adds just 12 feet of departure from the position of rest, to the 8 feet of vertical departure which is due to the half height of the 16-feet wave, so that the extreme departure of the assumed point from the position of rest, is in all equivalent to an oscillation ranging 20 feet each way, and having a period of (4″). Now in all oscillations governed by the isochronising law (which has been assumed to govern those we are considering, and which does govern them with sufficiently approximate correctness) the quantitative measurement of the maximum absolute force impressed or acting on the oscillating body (being that which operates at the extreme end of the range) is defined by the expression $F = \frac{\pi^2 S}{T^2 g} W$, where (T) is the period of the single oscillation; (S) its extreme range from the point of rest; (W) the weight of the body; and F the impressed

* This follows from what is said in my Paper, *Trans. I.N.A.*, Vol. II., p. 202. There is another possible, but less ordinary condition of uniformly maintained transverse oscillation, explained, *ibid*, p. 204-5. I prefer, however, for shortness and simplicity, to adhere at present to what I believe is the more ordinary as well as the more marked condition: it is easier thus to render intelligible the principles of the reasoning employed, while a full discussion of their application would form a Paper in itself, and had better be reserved for a future occasion, when I can supply it if necessary.

† It might seem more proper to assume a wave of greater relative height, implying a greater range of transverse, and therefore of derivative vertical oscillation; but in assuming the maintenance of a wave series of quite unchanging period, though of moderate height, I think I really adopt conditions quite as unfavourable in ultimate result as any which are likely really to occur.

force—while at any other point short of the extreme range, defined by (s) as its distance from the point of rest, the impressed force, $f = F\frac{s}{S}$.

Hence, in the case before us, where $s = 20$ feet, and $T = 4''$, we have $F = 0{\cdot}370$ W. That is to say, if a 96 cwt. gun be secured close to the ship's side, when thus acted on by the assumed wave series, including the effect of the 22° of rolling, it will press on the deck with a force, alternately of 60 cwt. when the ship's side is at its greatest elevation, with the ship on the wave crest; and 131 cwt. when it is at its lowest position, with the ship in the wave hollow.

The period, however, when the derived vertical oscillation reaches its maximum range, as has been already explained, is prior or subsequent to the transit of wave crest and wave hollow, by an interval of time corresponding with a quarter of the wave period, making the combined impressed force due to the two other causes, less in the ratio of $\frac{s}{S}$, or of sin 45°, reducing it therefore from 0·370 W to 0·265 W. At this period the impressed force due to the derived vertical oscillation (the fruit of the Symondite form), whose range is 6·27 feet, and period is 2″, will be $F = \frac{6{\cdot}27\ \pi^2}{4\ g}W = 0{\cdot}483$ W.

Thus the whole impressed force due to the combined effect of the three kinds of oscillation, acting together at this instant, which may practically be treated as their maximum,* amounts to $F = (0{\cdot}265) + 0{\cdot}483$ W $= 0{\cdot}748$ W. Hence, the 96 cwt. gun would virtually weigh alternately (96 ± 72) cwt., that is to say, 168 cwt., or 24 cwt.; and large as this variation is, the downward force of gravity would not it seems, even in this extreme case, undergo reversal.

It is of course true that the fore and aft oscillations of the ship in pitching will bring additional forces into play on some parts of her frame; but at the extreme ends of the ship, where the pitching motion acts with its greatest effect, her narrowed form limits the maximum rise and fall due to the transverse oscillations, and the transverse oscillations will be themselves less, since the waves, now oblique, must be acting less forcibly.

On the whole, therefore, I retain the opinion, that the stresses due to the derived vertical oscillation of Symondite ships are of a comparatively harmless kind, since they do not introduce a reversal of pressures on any part of the hull or cargo; while in regard to that class of stresses which is involved in the reversals of pressure inevitably

* The period of combined maximum, taken more strictly, is when the wave crest or wave hollow is approached a little more closely, making $\frac{\pi t}{T} = 50\frac{1}{2}$ instead of 45°; the maximum of the derived vertical oscillation is then somewhat passed, and that of the combination of the other two oscillations is somewhat more nearly approached; rendering the absolute maximum impressed force due to the three kinds of oscillation $F = 0{\cdot}759$ W, instead of $= 0{\cdot}748$ W, as given above.

involved in the alternate inclinations of a rolling ship, the Symondite will not experience these more severely than a ship of any other form, having the same general dimensions, and under circumstances which oblige it to make the same number of oscillations of the same range in the same time.

And while such special uneasiness as must be credited to these vertical oscillations, when they really occur, seems rather a matter of personal discomfort than of mechanical stress, the occurrence of the *exact* conditions which will develope them on the maximum scale, is not an inevitable consequence of the Symondite form, and can scarcely be accepted as the invariable explanation of the almost invariable experience that those ships which possess it roll widely and violently.

The real explanation of the circumstance, I continue to believe, lies in the fact that all the ships which have been built on this type possess an excess of stability, and consequently a short periodic time. This condition involves them more frequently in the excessive accumulations of angle which arise when the ship's periodic time approaches equality with that of the waves; and it at the same time renders all the changes of motion more violent from their being performed in a shorter period. I may add that in remedying this evil of excessive stability, we adopt the surest method of mastering also the tendency to accumulation in the derived vertical oscillations we have been tracing—for we at once lessen the primary oscillations from which these are derived, and we obliterate that specialty of relation between the periods of transverse and vertical oscillation, on which the tendency of the latter to accumulation depends.

In attempting to carry the reader through this (I must admit diffuse, and perhaps even laboured) discussion, I hope it will not be thought that I have been needlessly striving to maintain a position, the defences of which I have admitted it was necessary to modify; for I have no wish to evade the force of the admission.

But it not unfrequently happens, especially in the more elementary stages of the attempt to reduce into the form of a regular science, the principles of any art which embodies a large mass of valuable traditional experience, that the existence of some tendency which becomes soon apparent under scientific treatment of the subject, is found to tally more or less with some, perhaps, undeniable and important fact which has been empirically established. In such cases there is an almost irresistible impulse to connect the fact and the scientifically proved tendency, under the relation of cause and effect, with a confidence which the comparison does not really warrant; and in accordance with this impulse, the enunciation both of the empirical and of the scientific proposition, is very apt to be mutually moulded into an undue adaptation, and their relation becomes established as a *quasi* dogmatic truth.

Propositions and relations thus established, if treated with undue delicacy or

deference, become great obstacles to the progress of free enquiry, distorting the currents of fresh thought too determinately into old established channels: and it is under the impression that the theory of the rolling of ships was thus in many ways hampered, and that the use made of the proposition respecting the rise of the centre of gravity in a Symondite ship (which had come to be taken as a full scientific explanation of the peculiarities in the behaviour of such ships) was especially of this obstructive class, that I have struggled to show the real bearings of the proposition, and to explain how entirely it fails to perform the task assigned to it, even when carried out into a possible extension which was not dreamed of when the relation between it and the practical fact was first regarded as established.*

I now turn to the more important and substantial part of Mr. Scott Russell's Paper; where he explains the principle on which, in his view, the whole theory of the rolling of ships depends.

I must state his view somewhat in my own language, in order to bring it the more clearly into comparison and contrast with the view which I have myself advocated, and to which it is in one sense antagonistic, though in another sense the two views may be said to rest on the same ultimate basis, since they both rely on the well-established laws which are known to govern the internal motions of the particles of which a wave consists.

* Before I quit the subject of derived vertical oscillation, I wish to record my opinion that the development of such oscillations, in some degree or other, must take place during the transverse oscillations of *any* ship of whatever form—not merely of those of the Symondite type, or those in which a statical inclination involves a statical elevation of the axis of the plane of flotation.

During the statical inclination of any ship there must occur, as is well known, either a rise of the ship's centre gravity or a depression of the centre of buoyancy, or a result compounded of both, to such an extent as shall represent precisely the "work done" in creating the inclination. Now it would seem that even assuming this to occur wholly as a depression of the centre of buoyancy, there must yet exist at each instant during the inclination, a downward displacement of supporting fluid; and when this displacement takes place dynamically, it must develope reactions which have no inconsiderable relation to the forces which create them, and to the infinitesimal intervals of time to which their occurrence may be mentally apportioned.

The question thus raised appears to me an extremely difficult one—one to the solution of which, I, at all events, do not pretend now to see my way: and I have quite disregarded the principles which it involves, in the solution of which I have in the text sketched the result—which result has been founded simply on those principles by which the ordinary solution of the problem of direct (as distinguished from derived) vertical oscillations, is accomplished; depending on excess or defect in the displacement of the floating body, measured by area of plane of flotation and excess or defect of immersion, these being regarded as measures of the accelerating forces acting on the definite weight of the immersed floating body.

That other condition to which I now refer, is of a more purely hydrodynamical kind, and requires mathematical treatment of a higher order. Doubtless, it has not been overlooked by the many able investigators who have dealt with the question of oscillation in a fluid; and in now calling attention to it, I do not affect to point it out as new, but I merely wish to state my belief that its results may prove, under certain conditions, to be by no means insignificant, even as compared with those large results which grow out of the simpler and more obvious principle on which I have proceeded.

A true and full solution should probably in every case include the operation of both principles, which may, indeed, be found to have some simple relation of mutual analogy, such as to eliminate much of its *prima facie* difficulty.

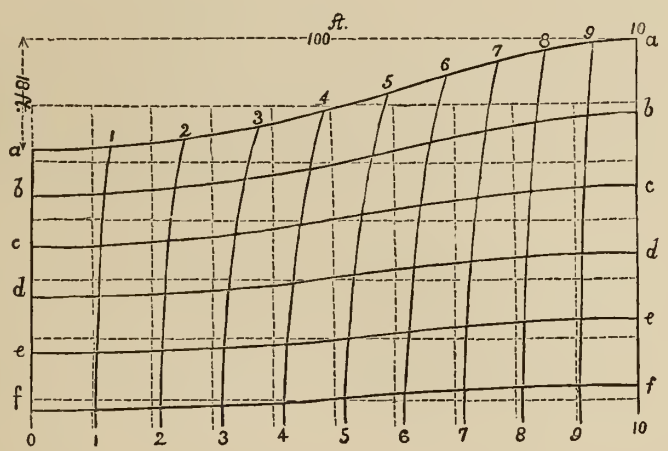
Regarding the difference between our views in the most general and broadest aspect, I might say that while I have relied, in the construction of mine, on the consequences of the average internal motion of the whole volume or mass of water which the ship displaces, regarding the mass as an integral portion of a wave, he relies on the consequences of the differences between the several motions of the several particles which make up the mass, regarding them as the differential constituents of the wave.

The paths of the particles of which a mass or volume of fluid affected by wave motion consists, are, as is obvious, compounded of vertical and horizontal displacements. If we take a series of particles which make up a vertical straight line in the fluid when undisturbed, it is now well known that when the fluid becomes penetrated by a regular series of truly recurring oscillating waves, the path of each particle in the series is a circle, simultaneously and similarly described by all, having its plane vertical, and at right angles to the axis of the wave ridge, and having its centre in the original vertical line, raised however to a small but definite elevation above the original position occupied by the particle when the fluid was undisturbed, the particle traversing the circle with uniform velocity. The originally vertical line of particles thus assumes a peculiar deflection.

If we trace out in turn, the simultaneous condition of a series of particles which, in the undisturbed fluid, occupied a horizontal straight line at right angles to the wave ridge, the positions of the particles taken together make up a trochoidal curve, whose horizontal length from wave crest to wave crest, is the circumference of the "rolling circle" of the trochoid, and whose height from hollow to crest is the diameter of the "tracing circle," and whose velocity of "wave propagation" is such, that the transit from wave crest to wave crest, occupies the same time as that which would be occupied in the double swing of a pendulum, whose length is the radius of the "rolling circle."

The radii of the successive circles, at successive depths, as we proceed down the vertical line which their centres occupy, are governed by a definite ratio, which I need not repeat here in full mathematical form since I discussed this fully in the Appendix to my remarks, published in the *I.N.A. Transactions* of last year, but which may be more generally understood, when translated into the statement that, if we proceed down the line of centres by steps, each of which equals one-tenth of the wave length from hollow to crest, the radius of the orbit traced from the lower centre in each step is 0·7304 × the radius of that traced from the upper. While if we travel along the line of centres, which are in the same horizontal straight line, the radii of all the orbits are the same; each particle occupying in its orbit the same relative advance of angular position as the centre of the orbit occupies in horizontal position.

If we geometrically represent the simultaneous positions of several such series of particles, we obtain a very elegant diagram such as was, I believe, first published in this country by Mr. Scott Russell in his Paper on Waves, read before the British Association in 1845, as illustrating and confirming the results of his own experiments, and as expressing the theoretical results of M. Gerstner to whom he attributed its invention. The diagram having this pedigree, was adopted as a type by myself, in illustration of the independent investigation of this particular class of wave motion, which I contributed to in the *Trans. I.N.A.* of last year, and to which I have already referred. And I must take this opportunity of apologizing publicly to Mr. Scott Russell, for an injustice which on that occasion I inadvertently was guilty of towards his edition of the diagram, in imputing to it a slight error: an imputation which, as I have since ascertained, arose simply out of an error made by myself in taking the measurements of his diagram, coupled with a somewhat singular circumstance which I need not here recite, though I have naturally mentioned it to him in part explanation of my annoying and much regretted blunder.



I give in the accompanying woodcut a transcript of so much of this diagram as is necessary to the present discussion; observing only, that though it may be regarded as strictly general in its features, I shall, in order to simplify and shorten the illustrative use I make of it, regard it as expressing the anatomical structure of a wave having a length of 100 feet from hollow to crest, and a height of 18 feet from hollow to crest—a somewhat exaggerated proportion of height, but one which I adopt, as giving rather increased force to the arguments on Mr. Scott Russell's side of the question, and as more nearly corresponding, I believe, to the diagrams which accompany his Paper. The dotted horizontal and vertical lines, at intervals of 10 feet to scale, represent the positions occupied by the several series of particles prior to disturbance; the corresponding strong

lines represent the positions assumed by these lines, in due relation to the phase of the wave. The interval of time which would be occupied by the assumed wave, in passing from hollow to crest, is 3·18″; and therefore 0·318″ is due to the transmission of the phase from line to line, so that on the lapse of that interval, No. (0) assumes the attitude of No. (1), No. (1) of No. (2), and so on.

Bearing in mind the relation between the geometrical and dynamical structure thus anatomized, it appears that at the bottom of the hollow, all the particles experience their greatest upward accelerating force and their greatest horizontal velocity, the motion being towards the advancing crest of the wave, or *against* the proper motion of the wave. At the top of the crest they experience their greatest downward accelerating force and their greatest horizontal velocity, which here is *with* the motion of the wave: at the middle of the advancing slope of the wave, they experience their greatest forward accelerating force and their greatest upward velocity; and at the middle of the receding slope they experience their greatest backward accelerating force and their greatest downward velocity.

As we trace any vertical line of centres downwards, and refer to the particles which describe the respective circles, the conditions of force and velocity just described, are experienced precisely in the same order or under the same phase; only that the translatory motions of the subjacent particles are less in range than those of the surface particles according to the law already specified, and the developed forces are less in the same proportion.

This difference between the velocities of the surface and the subjacent particles governs the curvature and direction of the deflected vertical lines; while along the deflected horizontal lines the curvature and direction are governed by the difference in the orbital progress of the successive particles, assigned to them by their position in the advancing wave phase.

It follows from this condition, if critically analyzed, that if we trace the intersections between the deflected vertical and the deflected horizontal lines, the deviations of the former from the vertical have a certain identical correspondence with the deviations of the latter from the horizontal; they are in fact precisely equal, the one to the other, when the point selected for the comparison in the deflected horizontal line is as far distant in point of time from the wave crest as the deflected vertical is from the wave hollow. Thus, in the woodcut, the vertical deviation of the line 1 1, where it intersects the line *b b*, equals the horizontal deviation of the line *b b*, where it intersects the line 9 9, the former intersection being as distant in point of time from the wave hollow, as the latter is from the wave crest.

Mr. Scott Russell refers the theory of the rolling of ships to the inferred behaviour

of two planks, subjected respectively to the two sets of deviations which these two sets of lines exhibit. The plank which would float upright, or on edge in still water, "is "absolutely prevented by the incompressibility of the surrounding water from main- "taining a vertical position during wave motion," and is thus obliged to conform itself to the deviations of the deflected vertical lines, so that its mast, if it carried one, would be always inclined *towards* the advancing or receding crest of the wave. The plank which would float flatwise in still water, naturally conforms itself to the actual wave surface, and would carry its mast, if it had one, always inclined *from* the advancing or receding wave crest. If the two planks are connected rigidly (the plank on edge at right angles to the middle of the plank laid flatwise), the opposing effects of the two, will tend to neutralize each other, and may be made to neutralize each other precisely, if proper proportions are adopted. And the same principle of neutralization may (again by proper attention to proportions) be applied with success to the construction of actual ships, the compound plank structure being (as an ideal) expanded, *mutatis mutandis*, into the body, gripe, and deadwood, which make up the hull; where the gripe and the deadwood, if of due dimensions, may be made to serve as an antidote to the tendency to roll, which the extended plane of flotation would seem to threaten.

I believe I have here expressed with substantial correctness, the view which Mr. Scott Russell takes of the conditions which seem to him to govern, fundamentally, the phenomena of the rolling of ships, and which, when developed into a theory, serve as his measure for estimating the comparative merits of ships of various form, and supply adequate rules by which such forms may be adopted as shall be exempt from the tendency to roll.

Now let me at once state that I regard the geometrical basis of the theory as unassailable, and that the theory itself, as a dynamical theory, is extremely elegant and captivating. But though I admit, or rather cordially assert, the truth of the geometrical basis of the theory, and though I am fully aware of, and (I believe) correctly appreciate the counteracting tendency of the forces on which reliance is thus placed (I might say *because* I am aware of, and appreciate it), I am satisfied, and I must endeavour to show that the dynamical theory is altogether delusive.

I shall *in limine* offer a remark which seems to me to indicate a practical and extremely forcible refutation of the theory. Why is it, if the theory is sound, that vessels built with due attention to it, ever roll at all? Why do vessels which Mr. Scott Russell names as examples of the successful application of the principles on which the theory rests, the *Great Eastern* and the *Warrior*, while steadily resisting the impulse to roll under certain circumstances, give way to it and roll severely under others? Why, again, should it be necessary to offer rules (as Mr. Scott Russell proceeds to do), for the stowage

of the weights which a ship carries? For since the external figure of a ship is in no way affected by subsequent stowage, that excellent proportion of parts which compels the mutually conflicting efforts exerted by the waves upon the hull to neutralise one another, ought to be equally effective however the weights are placed.

And though the allegation of this apparent inconsistency is not an objection of that definite and measured kind on which I desire the discussion to hinge (since it only indirectly points to what I conceive to be the grave defect of Mr. Scott Russell's theory), it may, at least, legitimately serve to embolden me in maintaining, on the basis of ordinary dynamical reasoning, views strongly opposed to the dicta which embody the long-tried experience of so high an authority.

I will state then what I conceive that grave defect to be. In doing this, I shall at the same time be bringing into close comparative examination the fundamental proposition of the theory which I have already advocated in former volumes of these *Transactions*.

(1). Mr. Scott Russell's view leaves absolutely no place for the operation of that force which in undulating water is brought to bear on a ship, by the appropriately modified condition, to which as an ordinary condition she owes her stability in still water. It will perhaps be said that when a position of absolute conformity to the wave surface, is ascribed to the plank which floats flatwise in still water, full credit has been given, under the modifying circumstances, to that extended surface of flotation to which the plank owes its stability in still water. But this can hardly be said with accuracy: for the tendency which obliges this plank to conform itself to the deflected horizontal lines is treated as exactly on a par, in respect of intensity and character, with the tendency which obliges the plank which was vertical in still water to conform itself to the deflected vertical lines; and since the latter is in express terms regarded as endowed with only just so much stability as will keep it upright in still water, we must infer that the stability possessed by the plank which floats flatwise is regarded as either non-existent or irrelevant.

Indeed, from the appeal made to the "incompressibility" of water, as the source of the constraint which obliges the plank on edge to conform itself to the deflected vertical lines, it would seem that this constraint is regarded as so masterful in its nature, that any co-existing force may be neglected, by comparison; for, though I am aware that the special term here applied is intended to be taken, not in its strict and absolute sense, but only in a sense such as to bring vividly before the mind the high scale of resistance which a plane surface experiences when we attempt to make it move orthographically through the water, nevertheless, the manner of its application proves, I think, that the relative importance of the force is greatly overrated.

It is true that in the latter part of the Paper, subtle distinctions are drawn as to the different kinds and sources of stability, and the behaviour of a ship among waves is said to depend on whether her stability is of one or other of the kinds specified. But these views are given quite irrespectively of that general theory just now traced out. On the one hand, the results of the theory as traced out are so perfect as to leave the whole question in need of no other treatment; and on the other hand, when the subject of stability and of its effect on rolling is treated of, nothing is said to shew that it impairs or modifies or reacts in any way on that equilibrated play of conflicting forces which is deduced from the consideration of the two planks, and is pictured as successfully and availably surviving in these planks, when combined and expanded into a full-grown ship.

(2). Another, as it seems to me, very grave defect in Mr. Scott Russell's theory is that it leaves no place for the operation of the circumstance or condition "moment of inertia" in the ideal planks, or in the ship into which they are expanded.

(3). Lastly, it appears to me to have been overlooked that when due effect has been attributed to the real and inevitable operation of the two conditions "stability" and "moment of inertia," the new positions which these impose upon the floating body will be such as almost to obliterate, certainly to confuse, the apparent simplicity and effectiveness of that *prima facie* correctly-balanced play of forces which the conditions of the two planks suggest.

I shall analyze in reversed order the several defects indicated, reserving to the last the questions hanging on or related to stability; partly because their discussion will unavoidably run to a greater length, and partly because the order thus observed will more nearly tally with that followed by the course of Mr. Scott Russell's remarks.

I will begin with No. 3. And as due weight, both absolutely and relatively, will be in turn assigned to the effects both of stability (in its primary form, and again as modified by the action of the waves) and moment of inertia, I shall here treat the planks as being both of them, in the first place wholly destitute of stability, and in the next place as having precisely the same moment of inertia as if their specific gravity were, throughout, identical with that of the fluid which they displace.*

Under these conditions, I shall assume the two planks to be placed in repose, the one flatwise and the other on edge, at or in the crest or the hollow of the wave on its transit. Thus limited, we may accept as practically, and within unimportant limits,

* This view may be accepted on the supposition that the planks are suitably weighted: such weighting would be simple enough for the plank on edge; but for the plank flatwise, we must suppose the plank itself to be almost destitute of weight, and its centre of gravity to be raised to its metacentre. But indeed it is quite sufficient if the view be held simply by an act of mental abstraction.

true, the proposition that the planks if separate will both assume alike during the wave transit, the attitudes respectively assigned to them, the one conformable to the deflected horizontal, the other to the deflected vertical line; and that if they are united, their efforts to assume these positions will mutually neutralize each other.*

In accepting, however, as undeniable the tendency on which the inference rests, it must be borne in mind that the principle which governs the tendency by no means defines those attitudes as being each (in a proper sense of the term) the "momentary position of rest" to the plank which assumes it.

What follows from the principle is simply, that if either plank for the moment occupies its appropriate attitude, it has inherently no tendency to deviate from this, and will resist with some force such a tendency when impressed on it from without; but it equally follows that if by such an impressed tendency it has been obliged to deviate, it has inherently no tendency to resume the attitude, and will equally resist one when impressed on it from without. In fact, when it has been thus disturbed from that order of successive positions to which it would have adhered, if undisturbed, it will simply continue to conform itself to the changing series of positions appropriate to the new aggregation of particles which it now displaces, as discriminatingly and as resolutely as prior to the disturbance it conformed to the series of positions appropriate to the aggregation of particles which it had displaced in the first instance.

All therefore that can be determinately said of planks floating under these conditions is, not that a plank floated nearly on edge, and another floated nearly flatwise, will tend, the one to become quite vertical, the other quite horizontal, at the top and bottom of the wave, and each to assume a certain defined set of inclinations at intermediate positions, but that each will tend to undergo a certain series of changes of inclination; the plank which was nearly on edge to undergo nearly the same series of changes as that which was quite on edge, and the plank which was nearly flatwise, nearly the same as that which was quite flatwise. And it is plain that in tracing the momentary effect of the tendencies possessed by the planks on the oscillations of a body more or less analogous to either of them (when this body is set in oscillation by some adequate cause), the important question is, not what position would be at the moment occupied by the analogous plank, but

* When the effort of stability, modified as it is by the conditions of wave motion, and tending to set the ship (no longer upright as regards the horizon, but) upright as regards the mean slope of the deflected horizontal lines, comes to be taken into account, it will be seen that the tendency of the plank flatwise, to conform itself to those lines, is greatly augmented in virtue of the stability it possesses from its extended plane of flotation; while, if the plank on edge be also endowed with stability (and it may be thus endowed by appropriate weighting, though destitute of extended plane of flotation), its tendency to conform itself to the deflected vertical lines will, by that same condition, be greatly impaired. It is this circumstance that altogether destroys the applicability of the equilibration of forces which we are considering, to the conditions of a floating body like a ship. This will be fully explained further on.

what change of position would the analogous plank be undergoing at that moment? Is that change of position auxiliary to or obstructive of those oscillations?

Thus analyzed, it appears that when imported into the special oscillations which are performed most nearly in a period concurrent or coextensive with that of the wave, and which are always the most formidable which can occur, the aggregate operation of the changes in position belonging to either plank, is extremely neutral; operating to aid the oscillation just as effectively during one half the interval of wave transit, as during the other half it operates to obstruct it.

Let us observe how this happens. When a ship is exposed to the condition which produces maximum rolling—that is to say, when the wave period is identical with her own—her maximum inclination towards the coming waves, occurs when she is at the bottom of the wave hollow, her maximum inclination towards the receding waves when she is on the wave crest. During the whole time she is on the advancing wave slope, her angular motion is from the advancing wave: now, during the first half transit of this wave slope, the changes of inclination in the plank flatwise are in accordance with those of the ship, those of the plank on edge are at variance with it, since the former is then inclining more and more from the advancing wave, and the latter more and more towards it; but, on the other hand, during the second half of the transit of the wave slope, the conditions are reversed: the plank flatwise is changing its inclination now no longer from but towards the advancing wave, and at variance with the motion of the ship, the plank on edge is no longer changing its inclination towards but from the wave, and in accordance with the motion of the ship: and the same series of comparisons may be drawn out between the changing inclinations of the ship and of the waves, on the receding wave slope. The action of either plank, integrated (so to say) during either half wave, is on the whole neutral if we take account of it in relation to the larger types of rolling.

There is, however, one type of rolling (but it is one which I think must invariably involve a limited range) in which the preponderance of either the vertical or horizontal plank element in the figure of the ship may produce a reiterated, and therefore, perhaps, a sensible effect.

In my original Paper on the "Rolling of Ships," *Trans. I.N.A.*, Vol. II., p. 205, I explained the conditions under which, on my theory, an oscillation of definite range might be maintained by a ship under the operation of a regular series of waves, when, though her own natural period differed from that of the waves, it would become altered into one which concurred with theirs; the wave impulses recurring in such precise order and proportion as to supply exactly that auxiliary force which would produce that alteration.

To originate such a series of oscillations, it is necessary that the ship should be upright at the transit of the hollow and crest of the waves, and should at the same time be moving with a definite angular velocity, governed by the ratio of her own period to the period and to the steepness of the waves. If thus engaged with a series of waves whose period is shorter than her own, it follows that in the hollow of the wave, her masts, though upright, are moving towards the advancing wave, with the angular velocity thus defined. If the wave period be the longer, the ship's masts, upright at the transit of the wave hollow, must be moving with the appropriate angular velocity towards the receding wave. In the former case, her roll is of course quicker and sharper; in the latter, slower and easier than her natural roll in still water. In either case the extreme range is reached when the ship is on the midheight of the wave. The full details of these conditions are drawn out in my original Paper, and I need not repeat them here. As there drawn out, they represent what would happen if the ship could oscillate without experiencing any resistance. But, though I have not attempted to determine precisely how such oscillations become modified, by introducing the condition of resistance, I think it is clear that the type of oscillation will not be specifically altered, though its range will of course be reduced.

This, however, is clear: in the case where the ship's period is thus shortened into conformity with waves whose period is shorter than her own, her angular motion is towards the advancing waves throughout the wave hollow, and from them throughout the wave ridge; and this alternation tallies in character with that of the plank on edge, and will come in to lessen the resistance of the water experienced by the vertical element in the ship's form. On the other hand, in the case where the ship's period is thus lengthened into conformity with waves whose period exceeds her own, the order of her motions will be precisely reversed, and will, in its character, accord with that of the plank flatwise, thus tending to lessen the resistance due to the horizontal element in her form. It is therefore probable, that if in the form of a ship vertical extension largely preponderates over horizontal (as it does perhaps in some of the very deep and comparatively narrow yachts—such as those which have earned a celebrity for Mr. Wanhill, of Poole), such a ship would be more than others apt to fall into an oscillation of fixed range with shortened period; while, for similar reasons, a broad flat vessel of light draft would be more than others apt to fall into such an oscillation with lengthened period.

It is only under these special circumstances however that the respective tendencies of the plank on edge, or of the plank flatwise, can either separately or in combination produce any marked and characteristic modification in the phases of the oscillations which we should expect a ship of given period to exhibit, when under the influence of a

given set of waves, acting on her through the instrumentality of her moment of stability alone, and under the limitation of surface friction and keel resistance, calculated irrespectively of those tendencies.

It is true that we cannot arrive at an accurately detailed integral measure of these retarding forces, except by tracing their differential or instantaneous values, and into these the conditions which govern those tendencies distinctly enter; nor do I seek to ignore this circumstance, or to undervalue it.* It is, however, plain that they enter only in the shape of minor alternations in the operation of a much larger alternating force; and it is obvious, on general principles, that the minor alternations cannot produce any material modification in the results of the larger, except in the cases where an approximate synchronism of impulse with motion gives a cumulative character to their operation.

In the case before us, this co-operative synchronism can only occur under the special circumstances just now explained; and here, possibly, when small waves are operating on a large ship, and when the proper range, and therefore angular velocity, of the oscillations due dynamically to the wave slope, are comparatively small, the effect of the condition may be relatively large.† But, under circumstances which develope oscillations of longer range, and therefore greater angular velocities, the direct consequences of the special conditions we are considering, must become relatively of less magnitude, and their chief importance consists in their tendency to engage a ship in oscillations of that particular type. On this point I will, however, only observe further, that in proportion as, by enlarging the surface of gripe and deadwood, we seek to give a preponderance to the vertical element of form, with the object of counteracting the tendency of the ship to conform her attitude to the wave slope, we develope a condition which renders her more likely to become thus engaged with waves having a quicker period than her own, and subject to alternations of force more violent and more frequently repeated.

I proceed now to the second of the points, in respect of which I said I felt Mr. Scott Russell's exposition of principles to be gravely defective, *viz.*, his omission to notice moment of inertia, as holding an important position among the conditions which determine the successive positions which a body will occupy when acted on by waves.

Even in relation to the typical forms whose behaviour he refers to as the basis of his general theory, the plank on edge and the plank flatwise, the condition is important; and its omission here paves the way for the disregard of it in relation to the

* I drew attention to the relevancy of these conditions to the question of resistance, in my paper on "Oscillating Waves," *Trans. I.N.A.*, Vol. III., p. 52.

† See *Trans. I.N.A.*, Vol. II., p. 209.

circumstances under which it plays a part of such very high importance, the behaviour of a weighted ship exposed to alternating impulsive forces. The proposition that either of the planks will accept the changes of motion of the particles which it displaces, and for which it is substituted in the wave mass, is indeed only approximately true under any circumstances; for the planks have not the mutability of form which the basis of the proposition, taken strictly, requires. Yet it is not even approximately true, unless the moment of inertia of each plank is the same as that which it would possess if it consisted throughout of a material of the same density as the fluid which it displaces: because the forces on either face of it are precisely such as to create those changes of motion which the intervening particles of fluid would receive if not displaced, and will therefore not impress those same changes of motion on the plank itself, unless the integral re-action (or moment of inertia) of the plank be the same as that of the particles displaced. If then the plank require ballast to make up the weight of the fluid which it displaces, we may, by concentrating the ballast near the centre of buoyancy, subject the plank to rather increased changes of motion; or *vice versâ*, by spreading it far from the centre, we may subject it to changes of motion almost indefinitely reduced, as compared with those which would have been impressed on the displaced particles.

It may indeed be said that the planks are to be regarded as infinitesimally thin, and that therefore the effect of specific gravity would vanish or may be disregarded; but if so, the conditions should reappear and be taken account of, when the planks are expanded into ships.

Again, it may be said that since the forces impressed on the two planks may be made to balance one another, and as the equilibration is assumed to be carried out into the actual ships by giving due proportion to the vertical and horizontal elements of form respectively, in her hull, the moment of inertia of each may alike be disregarded; but this can scarcely be regarded as a possible condition, since when the question of disposition of weights is treated of, it is not said that correctly proportioned ships are exempt from the necessity of attending to these rules. Yet even in treating of the disposition of weights no credit is given to moment of inertia as affecting the result—though the behaviour of a ship is referred to under circumstances where its functions must be very material, *e. g.*, where a ship is turning the crest of a very sharp wave.

I must pass on to what I have named as the foremost of the defects in Mr. Scott Russell's theory. I pointed out that in elucidating the basis of the theory by deducing and appealing to the behaviour of the two planks as acted on by waves, he appears to regard that property which in still water is called stability, as irrelevant or non-existent. In the subsequent part of his Paper, however, in which the disposition of weight is treated of, the effect of those conditions which yield stability in still water (metacentric

height, and height of centre of gravity) *are* dealt with; and the conclusion deduced appears to be that whereas, in still water, breadth of beam with a high centre of gravity, and depth of ballast with narrowed beam, may be made to yield exactly the same stability—and whereas again in still water, surface extension, and depth of ballast, are co-operative forces, in wave motion this identity of action, and this co-operation no longer exist, but the forces which were there co-operative, have here to be measured by contrasted rules: the effects of the two kinds of stabilizing force become characteristically different, and tend to impress different motions on the ship which possesses them.

I shall, therefore, myself trace the distinction which exists between the character of stability derived from these different sources, following as nearly as I can the line of thought suggested by Mr. Scott Russell: and though I am not able to accept the terms by which he defines the sources, and do not admit that a ship's behaviour in a sea-way will depend (as he infers) on the question whether her still-water stability is due to the one or the other of those sources, the distinction is no doubt one which it is well to appreciate and investigate.

It appears to me that the sources of stability, between which the distinction is to be drawn, and between which alone a real and fruitful distinction can be drawn, are not, as he expresses it,—(1), form, and (2), weight; but (1), form and area of plane of flotation, and (2), form and weight of immersed body.

It is, of course, possible that I do not rightly apprehend the meaning of the distinction, as he expresses it; because, as I apprehend it, there appears to me to be palpable error in his exposition. I refer to the following passage:—"In order to "understand the nature of stability of form apart from that of weight, we must place "the centre of gravity where it can have no action on stability; and for this purpose, "place it in the axis of motion, or in the centre of the water-line of the ship I am about "to describe." On this I must observe in the first place, that it is absolutely impossible to place the centre of gravity where it can have no action on stability: place it where we will, the measure of the ship's stability cannot be arrived at, except by taking account of the position. In the second place, place it where we will, the position of the centre of gravity itself is approximately the axis of motion; though the form of the ship may be such, that during oscillation it undergoes a rise and fall (the strict momentary axis being a point more or less distant from it in the horizontal plane which passes through it), and though the dynamic action of the surrounding fluid may simultaneously impress on it some small horizontal displacement. Apart however from these difficulties, which perhaps admit of explanation, I accept the general drift of the paragraph which follows the sentence quoted. The stability of a ship, regarded as a body which floats at the surface, and which has its centre of gravity in the plane of flotation, is the balance

of two conflicting forces;—(1), the negative stability of the submerged body, and (2), the positive stability of the plane of flotation, as a plane extended on the surface.

The latter of these forces may, in a true sense, be described as due to form irrespective of weight; but the former cannot in a true sense be said to be due to weight irrespective of form.

It will indeed appear that the character of the difference between these conditions as they affect the behaviour of a ship in still water, undergoes no such inversion in principle as Mr. Scott Russell maintains, when she is transferred to wave water. I must, however, analyze their operation in detail under both circumstances; first, because it is in regard to this very point that the gravest difference exists between his views and mine; and next, because though the difference proves, I think, on examination to be in itself irrelevant, it leads up to a third distinction which may be drawn between the stability of one ship and another, which is obviously relevant and important, and which, though Mr. Scott Russell does not in terms notice it, lies, I think, at the root of several of the views which he cites as established by common experience.

This third distinction lies in the difference between the angle of inclination, or range of oscillation, up to which this or that ship carries the regular growth in her moment of stability, or at which her effort to right herself begins to decline, and she runs into the danger of being capsized.

Let us first observe the conditions of stability belonging to a body wholly immersed, and loaded with a weight precisely balancing the support given by displacement. In this case it is obvious that the body will be unstable when the centre of gravity is perpendicularly above the centre of buoyancy, the perpendicular forming what may be called the axis of equilibrium; and that as the centre of buoyancy does not change its position in the body when the axis of equilibrium is forced to retain an inclined attitude (since that position is simply a result arrived at by an integration based on the solid figure of the body itself) the moment of stability is measured rigorously by the expression, $\mu = \mathrm{W\,M} \sin \theta$, at whatever angle of inclination; and this, being the force which tends to bring the axis of equilibrium right end uppermost, is in effect an oversetting force, and establishes a position of unstable equilibrium, when by a force externally applied the axis remains inverted. The wholly submerged body is in fact a body whose metacentre is fixed in position, that position being the centre of buoyancy.

Let us next examine the conditions of stability which belong to a mere plane of flotation—that is to say, a floating plane which has a thickness very inconsiderable as compared with its horizontal extension, and which I shall, for convenience, assume to have at least as much of its thickness out of the water as in it.

Here it appears, that within such small range of inclination as the thickness of the plank admits without emersion of its lower edge, the stability developed is irrespective of the thickness and weight of the plane; the effect of variation in its limited thickness and corresponding increased weight and immersion, being to vary, not the co-efficient of stability, but the range of inclination within which that co-efficient is applicable.

This is readily seen, if it be borne in mind that the displacement of the quasi infinitesimal wedges of immersion and emersion, as well as the horizontal distance through which their centres of displacement are transferred, will be the same for a given small angle, whether the plank be thick or thin: this supplies positive stability, and the negative stability of the small submerged thickness may be neglected.

Now that transference of displacement, represents a moment of stability, which as is readily seen is measured by the expression $\mu = \frac{1}{35} \frac{9\,\rho^3\,\mathrm{L}\,\theta}{4}$, where (ρ) is the radius of gyration of the plane of flotation round its longitudinal axis, (L) is the length of that axis, and (θ) (as equivalent to tan θ, the angle being small), is the angle of inclination, the co-efficient $\frac{1}{35}$ meanwhile representing the fact, that 35 cubic feet of salt water $= 1$ ton; and where, on the other hand, (μ) stands for the force in tons, which acting by a "couple" having one foot span, would maintain the inclination. The result, it will be seen is independent of the weight or total displacement of the floating plane.

The same conclusion is readily arrived at by transforming the ordinary metacentric formula, adapted to the case of a floating body whose sides are flat and whose bottom is parallel to the plane of flotation, by inserting the conditions that the thickness or depth is inconsiderable.

For the height of the metacentre of such body above its plane of flotation is given by the expression, $\mathrm{M} = \frac{3\,\rho^2}{4\,\mathrm{D}} - \frac{\mathrm{D}}{2}$, (D) being the immersed depth of the body, where we may put $\mathrm{D} = \frac{\rho}{n}$, (n) being some large number; and since the weight, $\mathrm{W} = \frac{1}{35} 3\,\rho\,\mathrm{D}\,\mathrm{L}$, the value of the moment, $\mu = \mathrm{W}\,\mathrm{M}\,\theta$, becomes on substitution and reduction $\mu = \frac{1}{35} \frac{9\,\rho^3\,\mathrm{L}\,\theta}{4} \left(1 - \frac{2}{3\,n^2}\right)$, where, if (n) be large, $\frac{3}{2\,n^2}$ may be thrown out of the account.

Thus if we were to take two planes of flotation identical in figure, but the one having $n = \frac{2}{3} \times 57{\cdot}3$, so that it would be capable of 1° of inclination without exposing any part of its under surface, and the other having $n = \frac{1}{3}\ 57{\cdot}3$ so as to be capable of 2° of inclination, in the former case $\frac{3}{2\,n^2}$ would be $= 0{\cdot}00046$, and in the latter $= 0{\cdot}00184$; so that if we

represent the moment, as before, by the expression $\mu = \frac{1}{35} \frac{9 \rho^3 L \theta}{4}$, it would in the former ease be in exeess by less than $\frac{1}{2}$ per thousand, and in the latter by less than 2 per thousand.

Now if we regard the floating body of the ship as made up of two parts, (1) the submerged body, cut off by a plane just below the plane of flotation, and (2) the plane of flotation of some small assumed thickness, the former being regarded as supporting the whole weight, we determine the whole moment of stability by deducting the upsetting force of the submerged body (for it is an upsetting force if the centre of gravity be above the centre of buoyancy) from the upholding force of the plane of flotation; and the determination thus arrived at may be accepted as valid, until the angle of inclination exceeds that which the principle of the reasoning on which it rests admits. The result thus arrived at is indeed identical with that reached by the ordinary method; but resolved as it is into two elements, the one depending wholly on the form and weight of the immersed body and on the position of the centre of gravity of the ship, and the other wholly on the shape and area of the plane of flotation, irrespective both of weight and of the position of the centre of gravity, some instructive if not praetically useful ideas grow out of the view thus presented. And so far as the view involves substantially the same ideas as those expressed by Mr. Scott Russell, I am glad to find myself on common ground with him, though the terms in which he expresses his ideas, if I apprehend them eorrectly, would not lead quantitatively to eorrect eonclusions.

The idea of a mere plane of flotation possessing a fixed eo-efficient of stability, irrespeetive of its thickness and weight, exeept so far as these enable it to earry the eo-effieient to a greater range, seems to me chiefly instructive as illustrating the character of the stability possessed by a broad and shallow ship, having a raised centre of gravity.

The characteristie feature of this is, that as soon as the gunwale begins to be submerged and the turn of the bilge to be emerged, the plane of flotation begins to lose breadth at its broadest part, and the inerements of the moment of stability due to each inerement of inclination, begin to fall off. As the inclination increases, the increments of moment pass through zero into the negative sign, and the stability itself at some moderate inelination becomes negative also. At that angle the ship will overset.

The eonditions here sketched have no doubt been fully investigated by Canon Moseley in relation to "dynamic stability," a property the consideration of which would soon bring them into prominence. These conditions, and not those which I have just before traced out, seem to me to have speeial importance in relation to the question of rolling, since it seems obviously possible that a ship whose stability is of the eharacter sketched, if exposed to an exceptionally abrupt sea during a deep weather roll or lee lurch (the

result of accumulated impulse) might be caught in a position of unstable or possibly reversed equilibrium, which might initiate a permanent overset before the transit of the wave phase could release her from the critical position.

I have now to establish the proposition, on the truth of which much of what has gone before depends, and which most markedly brings my views into conflict with those of Mr. Scott Russell.

The proposition in question is, that the momentary position of rest for a ship on a wave, that position which she at each moment seeks to assume, and which, by her distance from it, governs the changes in her motions, is practically independent of the question, whether her co-efficient of stability in still water be large or small; and again, of the question, whether, when the co-efficient is of given value, that value is due to the effect of an extended plane of flotation subject to a comparatively large deduction on the score of the upsetting force of the submerged body, or to that of a narrower plane of flotation subject to a less deduction on that score; in other words (to revert to the more ordinary modes of expressing the same ultimate facts), whether her metacentre be high or low; or again, whether she have a high metacentre with a high centre of gravity, or a low metacentre with a low centre of gravity.

I believe, that I have in fact sufficiently proved this, in my previous contributions to the *Trans. I.N.A.;* and it follows too, substantially, both from Mr. Crossland's Paper, and from Professor Rankine's. But it is probable enough that Mr. Scott Russell, and perhaps others, have either not read or not studied, or not appreciated the force of the reasoning on which the conclusion rests; contented with the belief, that as the conclusion when followed out, led to ulterior conclusions at variance with his or their long-established, and (as it seemed) well-proved convictions, some fallacy must be involved in it, which it was not even worth while to refute.

I now repeat the reasonings with only such variations in form as will best suit the considerations with which we have been already dealing.

Let us revert to the wave diagram, in p. 16; and let us suppose that throughout the mass of the disturbed fluid—let us say at each of the intersections between the deflected horizontal and deflected vertical lines—there exists a small sphere, having the same specific gravity as water, and having an infinitesimal spherical cavity in its centre, half filled with water or other fluid.

Each of these spheres, as substituted for the small volume of water which it displaces, is subject to the differentially varying forces which would have actuated that volume. We have seen that each such volume describes a circle round a fixed centre,

and under definite conditions of radius, and of uniform angular motion; and these conditions enable us precisely to measure that differentially varying force, as the direct resultant of the two forces which the motion of the mass implies.

The mass of each sphere is so supported, and so pressed by the surrounding fluid, that it continues so to describe that circle round that fixed centre. Therefore it is in the first place supported by a pressure equal to its own weight; and it is in the next place acted on, besides, by a force always urging it directly towards the centre of the circle, with an intensity exactly equal to the centrifugal force of its mass, regarded as describing the circle of that radius with that angular velocity.

The composition of these forces produces an inclined resultant of definite magnitude and of definite direction; and to each sphere, and to the infinitesimal volume of fluid in the centre of each, that resultant assumes by substitution precisely the relation which the vertical force of gravity would have occupied towards it in still water: the small enclosed volume of fluid will have its surface at each moment at right angles to the line of the resultant: a little plumb line, suspended within the sphere, will hang parallel to the resultant; and a particle of matter, let fall within the sphere, would fall through the sphere parallel to the plumb line.*

The directions of the enclosed fluid surfaces, thus defined in the spheres which float at the top surface of the wave, mathematically express, and in fact will be identical with, the direction of that surface, where each sphere floats. And in the subjacent spheres, their directions will similarly express and exhibit the direction of the surface of equal pressure which passes through each sphere. And if a series of tangential directions thus locally defined be carried out into a continuous curve, we shall in idea trace the course of a subsurface of equal pressure; that is to say, a surface along which if we were to test the pressure of the superincumbent mass of fluid by a gauge, we should find it to be invariable whatever were the size and shape of the mass. A curve thus defined, in the regularly formed oscillating waves of the type we have been considering, when mathematically analyzed, is identical with one of the deflected horizontal lines to which such frequent reference has been made; and the mechanical or dynamical

* The enclosed volume of fluid must be assumed small, and the plumb line short, because the particles of fluid and the plumb bob, in changing their positions, and adapting themselves to the changing directions of the resultant, must undergo independent motions, differing slightly from that of the centre of the sphere which carries them; and this circumstance tends to establish in them a minor series of subordinate oscillations, referable to the momentary position of the resultant as the position of rest, just as those of a pendulum on a fixed point of suspension are to a vertical line—or those of water, oscillating in a stationary cup, are to a horizontal plane.

The assumed smallness of the volume and shortness of the plumb line, supply the condition that the incipient oscillation will in each case be performed in a period indefinitely short; and that, in fact, the fluid surface will remain truly normal, and the plumb line truly parallel, to the resultant.

properties which it possesses are such that the whole volume of fluid penetrated by the waves may be regarded as a stratified mass, the strata being defined by the curves of equal pressure, so that each might be stripped off in succession from the fluid below it, without in any way disturbing the curvature or the motion of what remained.

The same idea of changes in fluid motion, as involving a new direction for resultant pressure, and a corresponding direction of fluid surface (whether of top surface, or of subsurface of equal pressure), the surface being always normal to the resultant and *vice versâ*, is readily admitted in relation to any type of wave, and is seen to be in fact characteristic of wave motion, when once the principle on which it depends is appreciated. In every case the virtual direction and force of gravity, as experienced by any particle of a wave, or by any particle of other matter, having equal weight and substituted for it, is the resultant of the natural force of gravity, and of the other forces which govern its changes of motion, and which are implied and measured by those changes. In every case the top wave surface and the subsurfaces of equal pressure are, and must be, alike at right angles to the resultant. The direction of the top surface or of the subsurfaces, and that of the resultant, are in fact exact correlatives of one another; either implies the other throughout the fluid. And further, while each momentary change in the motion (implying as it does a corresponding momentary force) thus fixes the simultaneous direction of the resultant, so in turn, the momentary direction of the surface, defining also the simultaneous direction of the resultant, implies the existence of such a change of motion, and of such a force as to produce that resultant.

It follows further that if on the surface of the fluid enclosed in one of the floating spheres, we were to place an infinitesimal model of a ship possessing stability, the model would seek to place its mast parallel to the resultant, and at right angles to the surface of the enclosed fluid on which it floats: or again, if one of the spheres were so weighted as to possess a definite axis of equilibrium, it follows that it would alike seek to place this axis parallel to the resultant and at right angles to the surface.

We have thus in fact arrived at the general proposition, that a stabilized particle whether floating on, or hydrostatically suspended in, the fluid mass of which a wave consists, will seek to place its axis of equilibrium normal to the surface of equal pressure which passes through it.

If instead of dealing with a single stabilized particle, displacing a particle of fluid, or with a single floating or suspended sphere, we deal with such an aggregation of these as will make up a floating mass (say the hull of a ship), it is manifest that the changes of translation impressed by the conditions of wave motion on the mass as a whole, will be the appropriate mean, or the resultant of those which would have been impressed on the several particles which the mass displaces; and that the forces which these changes

represent will be the appropriate mean of the forces which the several displaced particles would have experienced; and the resultant which expresses both the direction and the magnitude of that force, will be, in both respects, the mean of the several resultants appropriate to those particles.

To a floating body so circumstanced, therefore, it is plain that this resultant will be at right angles, not simply to the top surface, as it would have been had the body been extremely small, but to the appropriate mean of the several surfaces of equal pressure penetrated and displaced by the body.

To this changing resultant in undulating water, will the axis of equilibrium of any stable floating body seek to conform itself, as being its momentary position of rest, just as in still water it seeks to conform itself to a purely vertical line. Nor is there any single dynamical condition involved in the circumstances, such as to give rise to a specific difference in the mode of determining the direction of the resultant, or the momentary position of rest, according to whether the stability depends on plane of flotation or on the form and weighting of the submerged body, though of course the direction of the resultant will vary in some degree according to the preponderance of particles near the top surface, or deeply submerged particles in the volume displaced.*

And by whatever angle of inclination the ship may for the moment deviate from that position of rest, it is not the less the position that she will seek to assume, and towards which she will be changing her inclination, alike whether she be actuated by a high centre of gravity placed below a still higher metacentre, or by a metacentre even below the surface of the water, with the centre of gravity still placed beneath it.

Mr. Scott Russell indeed implies that a difference of a very important character hinges on this difference in the source of stability: but he does not state what that difference is, or how it arises; nor does he directly state, or as far as I can perceive indirectly intimate, what ought to be regarded as the momentary position of rest for a ship on the wave, or enunciate any principle which leads to its determination.

I only gather thus much, though perhaps I gather it not correctly. Judging from the nature of his reasoning, his view appears to me to be, that when a ship is inclined on

* It is true that if the floating body were not in structure rigid, but (let us say) a regular parallelopipedon while in still water, having however its sides and ends so jointed where they meet the bottom, as that the body should be capable of assuming freely a rhomboidal figure when it was acted on by waves, its sides would seek to conform themselves to the deflected vertical, and its top and bottom to the deflected horizontal lines shewn in the wave diagram. But such a mode of construction would entirely obliterate, or at least confound, the conditions of stability in still water. And on the other hand, if the sides became rigidly connected with the bottom, the respective tendencies of the sides and bottom when acted on by the waves would at once more or less neutralize each other, and at the same time the force of stability would be called properly into existence.

a wave, if the metacentre and the centre of gravity be high, their compound effect may be an absolutely oversetting force, though in still water it would be such as to provide ample stability; and on the other hand, that if the metacentre and the centre of gravity be both below the surface of the wave, their compound effect will tend to bring the ship into a purely vertical position, in spite of the wave slope.

How, and to what extent, his view of the function of stability, in relation to waves (if this be his) differs from mine will now be readily understood. But as I have already said, the propositions which he enunciates as the basis of a *prima facie* complete theory of the causes and nature of rolling, are drawn out as exclusive of stability, and these I have in the earlier part of this Paper examined as exhibited in the tendencies of "the "plank on edge" and "the plank flatwise."

And as I have myself expressed my belief in the existence of these tendencies, and have explained my own views of the nature of their operation, differing somewhat from Mr. Scott Russell's, it remains for me to explain further, how and in what degree they serve fundamentally to modify the operation of those other far more dominant tendencies, based on stability as exhibited under wave conditions, which in my view substantially govern the behaviour of a ship in a sea-way. I must, therefore, briefly sketch the working out of this view.

Adopting, on the principles just now explained, the position which places the ship's masts normal to the mean of the sub-surfaces of equal pressure displaced by her hull, as her momentary position of rest, I have reduced her momentary tendency to assume that position (her momentary change of motion towards it) into an equational form, by assuming that the force which urges her to pursue it when she deviates from it by a given angle, is the same in amount as that which would urge her towards an upright position in still water when inclined at that same given angle.*

Applying the equation of force thus arising, to the curve of sines assumed as the equation of the wave curve, there resulted a general equation of motion, shewing the changes of position which a ship, having a given period of rolling in still water, would

* There is an admitted defect in this assumption, since it takes no account of that variation in the ship's co-efficient of stability which depends on whether the accelerating forces impressed on the water on which she floats, add to, or diminish, the force of gravity, a condition in the water which I have named its hydrostatic tension (see *Trans. I.N.A.*, pp. 194, 195). The measure of this condition of force is expressed by the measure of the governing resultant, just as the direction in which the force operates is expressed by the direction of the resultant. The amount of error thus involved is not under ordinary circumstances large, and I have neglected it in framing the equation; with the less misgiving, since its omission seems in some degree to correct the effect of some other errors of somewhat similar scale involved in the assumption of the wave curve. The admission of the co-efficient which would correct this particular error, as well as the use of a more rigorously correct equation of the wave curve, rendered the equation of the ship's motion insoluble. See also Professor Rankine's Paper on the same subject, *Trans. I.N.A.*, Vol. III., p. 22, *et seq.*

undergo under the operation of a regular series of broadside waves, having a given period of recurrence and given dimensions, provided her oscillations were performed without resistance.

The character of these changes of position or oscillations has been frequently referred to in this Paper: but I may briefly describe it. Viewed as a whole, it consists of a series of recurring phases. Each phase comprises, first, a number of oscillations in which the recurring wave impulses are timed into harmony with, and add to, the existing swing of a ship, rendering the range of each consecutive swing larger. Next, an equal number of oscillations in which the wave impulses are similarly timed into discord with her existing swing, and obliterate it step by step as they had accumulated it. The impulses timed into harmony multiply in number, and the accumulation is great, in proportion as the periodic time of the ship is nearly equal to that of the waves. Exact equality of periods produces incessant repetition of accordant impulses, and incessant accumulation of swing. And even approximate equality produces a fatal amount of accumulation. The scale of the accumulation depends, *cæteris paribus*, on the steepness of the wave-slope. But, in fact, resistance intervenes throughout; and becomes an absolute check to accumulation, when the oscillation has received some sufficiently extended range, even though exact equality of period subsists; and I have given some approximate methods of estimating its effects.

According to this view, ships however dissimilar in form, and in the character and origin of their stability, would all alike tend to perform exactly the same oscillations in a given series of waves, if each had the same periodic time, and if the form of each were such as to make her still water oscillations isochronous* for large and small ranges; only it would happen that those ships which had the greater breadth and depth (more especially the greater depth) would find the virtual wave slopes less steep; the former by averaging the slope of the top surface (since all parts are less steep than the steepest), and the latter, because part of their displacement is made up of the underlying wave-stratification, which is less steep than that of the top surface; and hence, both, but

* With regard to the assumption of isochronism, I have offered some brief remarks in another part of this volume. I will here merely state that the form of a ship must be very unusual, which makes her deviate sensibly from isochronism, till the inclination is reached which either submerges the gunwale or emerges the turn of the bilge. If we compare two ships which have the same period for small oscillations, the one having an unchanging metacentre for all inclinations, the other having one which so rises when she becomes inclined as to make her oscillations isochronous throughout; if each were to perform an oscillation of 60° each way from the perpendicular, the period of that which had the fixed metacentre would exceed that of the other, by barely $\frac{1}{16}$. Of course a ship of very exceptional form would have to be dealt with by an exceptional method; but for small angles of inclination, up to 8° or 10°, no admissible form would produce a material deviation from isochronism; so that even the exceptional ship would *begin* to behave like the rest—the character of the deviation of her performance from theirs, when oscillations of large range are contemplated, could be easily estimated, by reference to the peculiarity of her form, though it would occupy much space to give general rules for estimating it.

especially the latter, would experience a less rapid rate of accumulation than their companions.

But when we further take into account the difference of specific resistance, or of the co-efficient of resistance, which the different ships may possess, according to whether they have keel or no keel, much or little gripe and deadwood, a round or a flat or a sharp bottom, we are introduced to a very important cause of divergence in their behaviour under given wave conditions, which will produce a marked effect on it even though the periodic times of all were the same.*

It is, as a circumstance interwoven with, and naturally forming part of, the general resistance experienced by a ship in oscillating, that I think the conditions indicated by the behaviour of the plank flatwise and the plank on edge, respectively, may be best viewed and examined. Thus viewed, it will appear that, as compared with the resistance which the ship would independently experience, the force thus attributable to

* It may not be out of place here to advert to a remark made from the chair by our excellent and very able Vice-President Canon Moseley, on his closing the discussion which followed the reading of Mr. Scott Russell's Paper. He observed in reference to the views which I had brought forward at previous meetings, that there was *prima facie* ground for hesitating to adopt them, in the circumstance that these views seemed to promise identity of behaviour to the smallest boat and to the largest ship, if only both were so weighted as to have the same period. What I have just said in the text as to the effect of the different degree of spread in plane of flotation, and of vertical penetration into the underlying strata of equal pressure, which is possessed by the larger ships, serves in part as an explanation of the difficulty which Canon Moseley suggests; since it shews by help of technical reasoning, what common sense at once apprehends and appreciates, that we must not expect a large ship to be much affected by comparatively small waves, though these may be large enough to produce formidable effects on a small boat. But probably it was the other aspect of the difficulty which Canon Moseley had in view,—namely, the difficulty of admitting that the behaviour of the boat and of the ship will be really identical when the waves are of extremely large dimensions, and when the equation would seem to be fairly applicable to both alike.

On this I reply, that the identity of behaviour promised as a practical consequence, is much less complete than a hasty reference to the mere form and terms of the equation taken alone, suggests. For (1) even in the largest waves, the greater spread and deeper penetration of the larger ship will have *some* effect in lessening the virtual steepness of the given waves as she will experience them: (2) the surface of large waves is almost invariably charged throughout with minor waves, of almost every intermediate dimension, and the behaviour of the small boat in respect of the large waves would in some degree be confused and disguised by the operation of these smaller waves, though the bigger ship would be insensible to them; (3) and lastly, comes the important condition, the resistance of the fluid to the oscillations of both the boat and the ship—a condition which would probably affect the two very unequally.

However, I ought to say fairly, I am satisfied that if we could obliterate resistance, and subject the ship to a series of waves just so much steeper at its top surface than those encountered by the boat, that their virtual slope as experienced by the ship (calculated with due regard to the slopes of the subsurfaces penetrated by her) should be the same as that of those experienced by the boat, I believe that the performance of the two would be identical.

But this conclusion does not seem to me inherently and in the abstract more incredible than, that a heavy and a very light weight, when suspended as a pendulum, will each perform an oscillation in the same time, if each pendulum has the same length between the centres of oscillation and suspension; or that an asteroid will perform its revolution round the sun in the same period as a large planet, whose mean distance from the sun is the same; or again (to take a more familiar, and at first sight equally surprising fact, in illustration), that a ton of lead and a single feather will fall at the same speed, in vacuo.

the element of her form analogous to either of the two planks, is relatively so small, and is so uninfluentially alternating in its general character; and that the two forces thus due to the principles represented by the two planks respectively, when estimated in combination (such a combination being in fact, inevitable), so far tend to neutralize one another, that no very marked effect can result from their operation, and no very material error will arise from disregarding it.* I shall not attempt to give even approximately a general solution of the laws which govern this element of resistance. I will only illustrate its scale, by showing how it will operate in one or two fairly selected examples, in reference to which it happens that quantitative statements are within my reach.

Let us take the case of the *Duke of Wellington*, as acted on by the wave exhibited in the diagram, Plate XVIII., Vol. III. Let us assume that her body is resolved into her vertical midship plane; but that this plane retains, as it assumably may retain, the co-efficient of stability which the ship herself, in her bodily form, possesses.

The dimensions of the wave are,—length, 100 feet from hollow to crest, and height, 18 feet from hollow to crest; and into this wave the assumed midship plane will penetrate 27 feet, taking the ship at her deep draught. The time occupied by the wave transit, from hollow to crest, is 3·18 seconds. Let us trace the operation when the ship is at the lowest point of the hollow,—the part of the wave where the change of inclination in the deflected vertical line takes place with maximum rapidity. The rate of change may be determined, either by comparing the horizontal velocity of the particles at the surface with that at the depth of 27 feet; or, by observing the change in tangential direction of the deflected vertical line, taken at medium depth, and occurring in a given interval of time.

The orbital radius of the surface particle is, in virtue of the wave height, 9 feet. So that its linear orbital velocity is $\frac{9\ \pi \text{ ft.}}{3{\cdot}18''}$, or 9·13 feet per second. The orbital radius of the particle at 27 feet below the surface is just 3 feet; so that its linear orbital velocity is 3·04 feet per second; thus the surface particle would be passing the bottom particle at the rate of 6·08—say 6·1 feet per second, representing a change of inclination equal to $\frac{6{\cdot}1}{27}$ per second.†

If we assume the plane thus circumstanced to be held in a truly vertical position by

* I must repeat here what I stated in my remarks, inserted in *Trans. I.N.A.*, Vol. III., p. 32, that it is in relation to the effect of resistance to rolling motion that the theory I have brought forward is chiefly defective; and while I am anxious to improve it in this respect myself, I shall regard with the greatest satisfaction any improvements which may be introduced into this (or, indeed, any other) branch of it by others.

† The intermediate curvature of the deflected line would represent, not a difference in mean angular motion, but a tendency to bend the vertical plane.

a couple, it would virtually perform an angular motion in the water, round its middle height as an axis, though, strictly speaking, it would be the water, and not the plane, which moved. The motion to be thus taken account of in the shape of the force which it would develope, would be a velocity of 3·05 feet per second at the extreme edges of the plane, declining to zero at its centre line.

Now, taking 100 lbs. per foot, as the resistance experienced by a plane moving orthographically through water with a velocity of 10 feet per second, so that $V^2 A$ represents the pressure in pounds on an elementary plane whose area is A in square feet, the elementary pressure on the edge of the plane would be $(3{\cdot}05)^2 A$; and at any other point, distant (h) feet from the axis, it would be $(3{\cdot}05)^2 \frac{h^2}{(13{\cdot}75)^2} A$, the velocity being as the distance from the axis: and the moment or torsional stress, which this would represent, round the central axis, would be $(3{\cdot}05)^2 \frac{h^3}{13{\cdot}75^2}$. Arriving by the usual method at the integral value of the whole moment developed on each half of the midship plane, we find $\mu = 90{\cdot}3$ tons, that is to say, the force developed on the plane when thus held stationary, might be represented by 90·3 tons, acting on a lever of one foot in length.

Now, the moment of stability of the *Duke of Wellington*, at her deep draught, is about 510 tons for 1° of inclination, that is to say, 510 tons acting on a lever 1 foot long, would hold her at an inclination of 1°.

Hence, the force which would be sufficient to keep the ship in an upright position, against the greatest effort which would be brought to bear on her midship vertical plane, by the water of so considerable a wave in its attempt to assume the position indicated by the deflected vertical line, is little more than one-sixth of what would be required to hold her against her natural effort of stability when inclined at 1°. It would, in fact, just hold her upright against the momentary effort of a wave having 10·5′ of inclination: whereas the mean wave slope, which the steepest part of our assumed wave would bring to bear on the ship were she held upright, would be about 13°, or near eighty times as great as the maximum effort delivered by the water resistance on the plane when so held.

It is true, the axis of oscillation in the real ship will pass, not through the centre line of her midship vertical plane, but through her centre of gravity near its upper edge, giving an enhanced moment to those relics of the plane which survive in her keel, gripe, and deadwood: but as her breadth is more than twice her depth, the horizontal element preponderates largely over the vertical in the rest of her form. The effect of either element must be small, and the balance of their compound effect, trivial.

But lest this mode of estimating the result should be regarded as inaccurate and unsatisfactory, we may examine it from another point of view, by observing what is the

whole resistance experienced by the ship in rolling in still water, the combined effect of surface friction and of all obstructive features, including those of both horizontal and vertical extension; and if we can arrive at a measure of this, for an oscillation in which the angular velocity corresponds with the maximum angular velocity of the deflected vertical line (let us say in the wave we have been considering), we shall know that the special force of torsion which the vertical element of form, singly, could deliver on the ship when held in a vertical position (in virtue of the analogous tendency of the plank on edge), must be very much less than that which the combination of all the elements of resistance deliver on the ship while rolling.

I have succeeded in constructing an extremely delicate (I might almost say a perfect) self-acting apparatus, for recording by diagram, the degrees by which the oscillation of any given model declines, when it has been held over at an inclination and released in still water: though I have as yet taken but few diagrams with it, I have a very beautiful one, taken off an accurate model of the *Great Eastern*, the scale of the model being one tenth of an inch to a foot. Such a model, if duly weighted, should have, and has, a period of $\sqrt{\frac{1}{120}}$ of that of the ship herself; or about 0·548 seconds.

Under these circumstances, the diagram informs me that the ship herself would have the same angular motion, as the deflected vertical line at its period of maximum change, when she rolls from an angle of about 27·7°, if we take her mean angular velocity through the greater part of the swing. It informs me further, that the resistance experienced during the swing, destroys just 3·7° of range, so that the succeeding swing ranges only to 24°.

The resistance has therefore destroyed so much of the *vis viva* of the oscillating mass; and if we take account of the space through which it acts, we can determine its absolute moment.

Now the diagram records the *vis viva*, or work, stored up in the ship at the 27·7° of inclination, as $\left(\frac{810}{2} \times 31{\cdot}4\right) = 12{,}700$ foot tons; and that at the reduced inclination of 24° as $\left(\frac{705}{2} \times 27{\cdot}1\right) = 9{,}550$ foot tons.

There is therefore lost by resistance during the oscillation, work to the value of 3,150 foot tons, the difference between the two figures above given; and this measures the force of the mean resistance due to the velocity acting through the space traversed at that velocity.

The force and the space may be referred to any radius which is convenient. I therefore take the result simply by measurement from the diagram, where it appears that on a radius of 65 feet from the centre of motion, a space of just 50 feet is traversed at the

mean angular velocity equal to that of the deflected vertical line which is the object of comparison.

If then, we call the resistance in tons due to this mean angular velocity, referred to the 65 feet radius, (R), it follows that 50 R = 3,150, or R = 63, and this resistance when referred to 1 foot as radius becomes 65 × 63 tons = 4,090 tons; that is to say, 63 tons, acting on a leverage of 65 feet, or 4,090 tons on a leverage of 1 foot, would just maintain the velocity unimpaired.

The co-efficient of stability represented by the conditions of the experiment, gives 1,910 tons referred to a leverage of 1 foot, as due to 1° of inclination, and thus the 4,090 tons would serve to hold the ship at an inclination of 2·12°; in other words, the whole resistance experienced by the ship, when moving with the angular velocity equal to that of the deflected vertical line at its maximum, would amount to a force capable of holding her at 2·12° inclination, and thus is less than one-sixth of that which the maximum wave slope would bring to bear on her if held upright in opposition to it.

In estimating the effect of this conclusion on the question, "How much force will "be developed by the gripe and deadwood of the ship, in so considerable a wave, in "virtue of the tendency attributed to the plank on edge, when she is held upright in "opposition to it?" we must bear in mind that the force calculated as above, includes all the resistance of whatever kind offered by any part of the ship, as well as that of the gripe and deadwood; and that her very flat floor, and great beam, and somewhat prominent bilge, besides skin resistance, must be regarded as responsible for a very large share of the whole resisting force developed during the oscillation.

In the still-water oscillation all these forces co-operate, acting in one and the same direction; and those of them which correspond with the tendencies attributed to the plank on edge and the plank flatwise, respectively form but a portion of the whole.

The theory, therefore, which regards those tendencies as substantially embodying the essential dynamical principles which govern rolling motion, in effect assumes this: that two tendencies, of not very unequal magnitude, which, when taken as acting in conjunction, form but a portion of a whole, in which they co-operate with others of undeniable importance, can, when acting in opposition to each other, control, or if need be, absolutely master, by their difference, the operation of another wholly distinct single force, above six times as great as the aggregate of which they formed but a portion when they acted in concert.*

* It is as well to answer, by the way, an objection that may occur to the reader who may not have become familiarized to the conditions which at once supply the answer: Does an experiment of this kind (however carefully and exactly made) justify the inference, that the proportions of force and resistance which a small model exhibits, will hold good with the ship which the model represents? Now, it is obvious that the actual moment of force possessed by the ship at a given inclination,

Perhaps I should apologize to the reader for multiplying proofs of a view, which those I have already adduced, have, in my own opinion, abundantly established. I am conscious too that there is a kind of unfairness in the appeal to actual fact, since I am confident that Mr. Scott Russell has hitherto relied, as I had myself done till recently, either on mathematical reasoning which he has regarded conclusive, or on experiments which, if indirect, he has considered to be really relevant and sufficient. But, bearing in mind the importance of the subject under discussion, and our mutually declared desire to arrive at truth alone, I think it right to make the appeal. I have carefully observed in sea waves the behaviour of the following bodies, adapted to the precise line of thought which the discussion has followed:—

(1.) A plane, 3 feet long by 10 inches deep, so loaded as to float on edge in still water.

(2.) A plane of the above dimensions floating flatwise, having a midship plane 3 feet by 10 inches, rigidly fixed at right angles to it, along centre line beneath.

(3.) The same as No. (2), only with the midship plane reduced to 5 inches in depth.

(4.) Two planes, 3 feet long by 10 inches broad, intersecting each other at right angles lengthwise centrally, having all but total immersion, with one plane flatwise, the other on edge.

(5.) A hollow tin cylinder, 2 inches diameter and eight inches long, having a tin plane, 5 inches deep, attached to it lengthwise and centrally beneath, with a bar of lead at its lower edge, of such weight as to produce all but total submersion of the hollow cylinder.

(6.) A hollow india rubber ball, $7\frac{1}{2}$ inches diameter, with a flat spheroid of lead

will exceed that possessed by the model at the same inclination, in a ratio expressed by the fourth power of the scale, since it will be in the compound ratio of the absolute weight and the metacentric height.

But the moment of resistance of the ship, when performing an oscillation of given range, will, alike, exceed that of the model in the ratio expressed by the fourth power of the scale; since it will be in the compound ratio of the square of the velocity of motion, the areas on which it acts, and the leverage with which it acts; where the areas are, of course, as the square of the scale, the leverage simply as the scale, and the square of the velocity also simply as the scale, since the periodic time is as the square root of the scale.

Hence, since the moments of force and of resistance follow the same power of the scale, if we express the mean resistance to an oscillation of given range, when performed by the model, by the inclination at which a force equal to it would hold the model statically, it follows that the force which would hold the ship statically at that inclination, equals the mean resistance which she would experience while performing an oscillation of the same range. Only it is to be observed that, if Beaufoy's experiments are to be relied on, friction, or skin resistance at all events, is proportioned to a power of the velocity somewhat less than the square; and as a rule, resistances as ascertained by models, are rather in excess of those which their scale prescribes, though hydrostatic conditions of force may be determined by models accurately: it is, therefore, to be inferred that, in applying the results thus deduced from the model of the *Great Eastern*, to the ship herself, we may expect that the resistance experienced by the ship in rolling will be, relatively to her dynamic stability, smaller than that indicated by the model.

carried firmly beneath it at a depth of 14 inches from centre to centre, the weight being such as to produce all but total submersion of the sphere.

The planes in 1, 2, 3, 4 were of $\frac{3}{4}$-inch elm, and were so ballasted with lead as to produce all but total immersion—the planes flatwise at the surface in 2 and 3, being immersed to half their thickness.

Each body was provided with a pair of crosstrees close to the water, so as more appreciably to mark the deviations of the plane of flotation from the wave surface.

I have unfortunately not been able to fall in with regular waves free from wind; and all the bodies, without exception, gave more or less indication that the sharpest of the wave crests particularly, but that all the wave crests in some degree, were being pushed over by the wind in advance of the true wave motion.

Thus it happened that No. (1), though in the hollow of the wave, shewed a disposition to conform to the motions of the deflected vertical line, began to lean in the reverse direction before the wave crest reached it, and was often thrown on its side by the transit of the crest, and was retained in that position by mere surface stability, unless its ballast had been pretty deeply stowed; while with the ballast pretty deeply stowed, so as to overcome this tendency, the stabilizing tendency of the ballast, in part mastered the efforts embodied in the deflected vertical line, and thus partly urged the plane into normality as regarded the wave slope.

In No. (2), the ballast was brought close to the intersection of the planes, and was considerably above the centre of buoyancy, so that the stability due to plane of flotation should be in some degree lessened rather than enhanced. In spite of the attached plane on edge beneath it having a depth equal to its own breadth, the plane of flotation retained its parallelism to the wave surface, except when subject to such abrupt transitions of form, that its mere deviation as tangential plane must have been considerable; or when the transit of a wave crest of unusual sharpness, by being overblown, as just now described, led to a marked elevation of the weather edge. There were, however, as all the observers thought, indications of an effort developed by the midship plane to conform itself to the deflected vertical line, though these would hardly have been noticed, except by a comparison with the behaviour of No. 3.

In No. 3, the plane flatwise on the surface seemed to hold its own, and conform itself to the wave slope, except when as in No. (2) the abrupt transitions of form rendered conformity impossible. It was, however, evident that the diminished depth of fin below rendered it capable of assuming new positions more freely than No. (2) had been.

No. 4 seemed on the whole to experience very little disturbance: it was so ballasted

as to give it a minimum of stability; but it too, when at the transit of a sharp wave crest, marked by its motion the fact that the crest was being overblown.

No. 5 kept its crosstrees on the whole parallel to the wave slope, though since, in spite of its having no plane of flotation which could supply additional stability, its deeply stowed ballast rendered it very stable, and gave it a very short period of oscillation, there was impressed on it a sudden effort to adapt itself to every abrupt slope which it encountered.

No. 6, was in fact a counterpart of No. 5, except that it was of larger dimensions, and was in its complete form a solid of revolution, instead of having extension in one direction as No. 5 had.

This circumstance exempted it from a difficulty which had been more or less experienced with all the other bodies in some degree, but especially with No. 5: the difficulty of keeping them broadside to the waves.

The whole effort of No. 6 appeared to be a vigorous effort to keep its axis at right angles to the wave slope; and though the general roughness of the surface kept it for the most part in rapid oscillations of short range, so that frequently it was only possible to note (not its actual position, but) the position it tended to assume, the tendency itself was unmistakable, and now and then a long clear hollow and ridge were met with, in which the position of rest was accepted determinately.

If I except the phenomena referable to what I have called the overblowing of the wave crests, the conclusions established by these experiments are exactly those which I have been striving to establish by reasoning. These phenomena indeed may require special investigation: it is probable that when occurring on a large scale they originate the danger which, Mr. Scott Russell says, arises from sharp-crested waves. But they do not on that account invalidate the reasoning based on the phenomena of true wave motion, of which they form no part.

That reasoning shews what are and must be approximately the ordinary phenomena of rolling as exhibited by ships of average form; depending in each ship, so far as impulse is concerned, characteristically and almost exclusively, on an easily ascertainable, and for the most part governable condition, the ship's natural period of rolling in still water: and so far as limit is concerned, on the specific resistance which the ship makes to transverse oscillation, a condition which is also ascertainable, and which may to some extent be governed by the naval architect.

That a ship which "behaves badly," will "make very bad weather of it" under circumstances from which a better behaved ship will suffer little, and that this will

happen irrespectively of an encounter with sharp-crested waves is perfectly well known. And it seems to me beside the mark, to combat a theory which gives a fair explanation of the differences on which that difference of behaviour depends, by alleging that other critical circumstances may arise, involving, let it be granted, serious risk, of which that theory takes no account.

There is, however, no reason for asserting that the rules which that theory would lead us to adopt as useful in regard to the more ordinary phenomena, will lead to danger in relation to these exceptional ones.

At least, I do not see that Mr. Scott Russell gives any reasons for the assertion, though he seems to make it. He simply lays down the maxim that a high metacentre and high centre of gravity involve danger. But he gives no reason, though he implies that there are reasons which justify the maxim.

And on the other hand, I have nowhere advised that the metacentre should be kept high. I only advise that if it is high, the centre of gravity should not be kept further below it than is requisite for the ordinary duties of carrying sail or the like. And, of course, if I were dealing with a vessel so shallow as to lose her co-efficient of stability when she has attained a moderate inclination, I should use with caution a rule which would indeed be safe for vessels of ordinary figure, but which might be dangerous there.

Nor do I recommend enlarged period of oscillation, as a panacea available for ships of all sizes, for none but the largest ships can hope to have a period materially larger than that of the largest ocean waves: I only say that the larger a ship's period is, the more seldom she will experience the trying conditions of synchronism, and the less abrupt on the whole will be the waves with which she synchronizes—for on the whole, large waves are less abrupt than small ones. What is wanted to give completeness to the theory is to find out available methods of developing in the highest degree the resistance of a ship to transverse oscillations, so as to use up the work which recurring wave impulse tends to store up in accumulated oscillation.

I feel that some apology is due from me for the great length to which this Paper has run, the more so as I cannot doubt that what I have had to say might have been rendered clearer by being put more concisely; but the real importance of the subject will excuse many shortcomings in the manner of treating it, if the views brought forward are in the main sound.

What, however, I shall chiefly regret are any lapses by which I may have fallen into a controversial tone. It is not so easy to detect such blemishes while one is in the act of writing, as it is to perceive and be sorry for them on leisurely perusal. I can only say I have been anxious to guard against them.

POSTSCRIPT TO MR. FROUDE'S REMARKS ON ROLLING.

By J. Scott Russell, Esq., F.R.S., Vice-President, I.N A.

I have read the foregoing Remarks with pleasure and instruction. The behaviour of ships on stormy seas is so hard to be understood and so important to be predicted, that it is worth any amount of hard thinking, and painstaking observation, and subtle reasoning we can expend on it. I cannot think it otherwise than an advantage for our common purpose—the advancement of the professional science of naval architecture, that Mr. Froude and myself should look at some parts of this difficult subject from opposite points of view, because I am sure that the more these difficult subjects are investigated by different minds working different ways, used to different methods, and starting from different points with the same purpose, the more rapidly will our convergent lines of thought work out the exact truth.

Already, in writing his remarks on my views, Mr. Froude appears to have obtained the impression which he seems to me to express in the end of his Paper, that his views and mine differ more in expression than in thought; and I confess that I rise from the reading of his Paper feeling that we differ less than we seem, and that both of us see clearer from the arguments we have undertaken. So strongly do I feel this, that as a mere argument I should be content to leave our two Papers to go forth together exactly as they stand, without addition on my part. The disadvantage of doing this, however, would be to leave an impression on the minds of those who have not given the question as much thought as ourselves, that we had left the subject much less settled and much less certain than we have done.

I shall, therefore, endeavour to shew the exact state in which our argument leaves the question, by a summary statement of the more important points on which we seem to agree, and those on which we seem to differ.

1.—Regarding the waves of the sea, their formal phenomena, and physical mechanism. In our respective views on this subject I cannot detect at any point an iota of difference between us. In regard to the forms of wave, they are all of the family of the cycloid. The strata which were horizontal at rest have become cycloidal in motion and are no longer parallel trochoids, but as they go down into deeper water, retain the same length of wave with a rapidly diminishing depth. And this law of diminution with the depth is also exactly known. So far as to the form of the waves. Next, as to their mechanical nature. Each particle of wave water moves in a circular orbit in a vertical plane, in a period of revolution completed with each wave length: the radii of the orbits diminish rapidly with the depth of the centre below the surface, but the period remains

constant. Thus then, each water particle performs a revolution like a planet, and is continually under the influence of gravity; of the water under it which supports it, and on either side of it which carries it forward and backward, and of its own centrifugal force belonging to revolution. Thirdly,—These forces and these motions in the particles, are entirely reconcilable with the continuity of the fluid and of wave forms which it assumes, and when we take into account the phenomena of a continuous non-compressible fluid, the mechanical forces of the independent water particles each moving in a circular orbit, we find these not merely reconcilable with the cycloidal forms of wave motion, but we are also able to shew how they necessarily and inevitably produce them.

On all these points and peculiarities of wave motion, we have complete agreement among the following authors:—My own investigation of the waves of the second order, from 1835 to 1845; Gerstner's wave theory; Mr. Crossland's investigations, 1862; Mr. Froude's investigations, 1862-3; Professor Rankine's, 1862. In regard to all these there is no difference that I am acquainted with either of fact or of opinion.

2.—Regarding the rolling of ships on the sea when at rest. I am not aware of any difference that does or can exist among those who have studied the oscillation of ships about the more general characters of the oscillation of vessels in still water. The principles of statical stability enable us to state exactly what are the measures of the forces which tend to restore a floating body which has been heeled over, to its original position of equilibrium; and that it will perform small oscillations on either side of it, just as a pendulum performs its swing through small arcs. Secondly,—We know those swings to be isochronous. Thirdly,—We know that the measure of the force producing these oscillations is conveniently expressed by the mass of matter into the height of the metacentre above the centre of gravity of the floating weight. Fourthly,—We also know that the force retarding these oscillations is the mass to be moved taken at its centre of gyration. Thus we obtain by a simple and common formula the period of the oscillation of a ship in smooth water. It can hardly be said that there has existed on these points from the time of Bernouilli and Euler, down to the investigations of Moseley and Dr. Woolley, Mr. Froude, and myself, any difference of opinion.

3.—Regarding the stability of ships on wave water, and the rolling of ships on wave water. Here the following questions arise. First,—Whether vessels that stand steadily square to the surface of still water, will stand equally square to the surface of wave water? Secondly,—Whether, ships set to roll on smooth water would continue to roll in the same way relatively to the surface of wave water? Thirdly,—Whether any new results would arise out of the combination of wave oscillation with independent ship oscillation? Fourthly,—Whether ships, with the same periods of oscillation, can have different sorts of oscillation? Fifthly,—Whether the shape of a ship with a given

metacentric interval and fixed weights, can affect the period of its oscillation, or the nature of its oscillation, in any other way than is already represented by the metacentric interval? Lastly,—Whether the metacentric interval being the same, the disposition of weights in the ship, above or below the water-line, can affect the movements of the ship and alter her behaviour on the sea?

I. Whether vessels that stand steadily square to the surface of still water will stand equally square to the surface of wave water?

I think we are agreed that a wide shallow float lying on the surface of the water—say half in, and half out—would maintain its position parallel to the skin of the water with equal tenacity on still water and on wave water. It is to be observed however, that such a vessel must be considered as one of an indefinitely high metacentre, and that its centre of gravity is to be taken as placed in the water-line. I take the height of the metacentre above the water-line as the measure of the force with which this floating body tends to keep itself square to the wave water surface; and so far as this case is concerned, I do not think we differ.

II. Whether ships set to roll on smooth water would continue to roll in the same way relatively to the surface of wave water, is a question on which we should entirely agree within the narrow limits of the hypothetical case set up by Mr. Froude. Taking his very narrow thin float, taking his waves without crests, pure curves of sines, and taking his oscillations very small and isochronous—then, certainly, the oscillations of the float, which were isochronous on still water would remain isochronous on wave water, and the oscillations of the ship would be of a cumulative nature, so that in the case of an equal period of oscillation of the ship and oscillation of the water, the oscillation would continually grow, and in case their periods differed, would alternately wax and wane at different epochs corresponding with periodic coincidences of oscillation. All that is a legitimate and evident consequence of the coincidence of the theoretical oscillation of the ship with the theoretical oscillation of the wave. It is this cumulative effect on which Mr. Froude so strongly insists; and the phenomenon is both true and beautiful. Now, on this point, what I say, and where I differ from Mr. Froude is, that his theoretical float is not a ship, and his hypothetical waves are not a sea; and I go on to say, that in a true sea his ship will behave very differently from what he supposes, and that a true ship on any sea will behave very differently from his theoretical float. Into the explanation of these difficulties I must go very shortly and very categorically.

His float is not a ship, because it has no draught of water and infinite stability; because it has infinite stability its movements will absolutely coincide with those of the surface of the water on which it floats; and on account of its extremely small draught of water, it will not be able to set up oscillations of considerable range of its own.

Mr. Froude's waves are not a sea, because they are as round at the top as at the bottom; and when the true sea rises and becomes dangerous, his float will be upright and upside down alternately. During one oscillation of the wave upright, and during the next upside down.

III. If we now leave Mr. Froude's thin float and hypothetical wave, to take a ship of considerable depth in the water, we obtain a ship which has moderate instead of infinite stability. That ship will now be capable of rolling with a long period and a considerable range, but it will have ceased to be Mr. Froude's theoretical float, both for that reason, and also because the lower part of the ship will lie among wave water, whose pressures on the lower part of the ship will be no longer conformable to those at the surface, and the action of the waves on the bottom of the ship will coincide both in direction and quantity with waves of a totally different height and inclination to those at the surface.

I have proved that the deeper and narrower a ship is, the more will it differ from conformity to the wave surface, and that in the same ship those parts of it which have great breadth relatively to their depth, will be strongly acted on by the waves to keep them normal to the surface; while those which have great depth and are thin and narrow, as at the bow and the stern of a fine ship, will have a strong pressure from the water, tending to keep them in a very different direction. This difference of direction of the two classes of wave action is so great, that precisely at the moment when, on a true sea, Mr. Froude's action would overturn the ship, mine would tend to keep it vertically upright.

I have hitherto spoken only of the action of the water on the ship, which I call stability of form, and in order to separate it from stability of weight arising from the disposition of weight within the body of the ship itself. In regard to this action also, I agree with Mr. Froude that, if the centre of gravity of the shallow ship be in the surface of the water or near it, the mass of the body will have a common movement with the mass of water whose place it occupies; and I quite agree, that the weights in the ship will have the line of their action in the normal to the surface of the wave, and that these weights will be for the moment in all respects as the weight of so much water in the wave. In the effect of weight in a floating body and its direction of action in wave motion, we are therefore agreed: but what I state is, and I state it strongly, that when the centre of gravity of the ship is much removed from the water-line above or below, its movements in that position will be very different from its movements when it lies in that plane; and that these differences will give to a vessel which has either a very high or a very low centre of gravity, very bad, and very unwholesome motions in a sea-way.

On this last point it is that he and I come to very important issues on practical points in shipbuilding, which materially affect the shipbuilding and seaworthiness of a

ship in a stormy sea. He recommends for insuring the safety of a ship, as a practical measure, that it shall have given to it such a disposition of weights, as shall insure to it a long period of oscillation, and he adheres to this maxim under conditions, and to an extent which to me appear dangerous and unsound. Thus, if a ship have a high metacentre, or what I call very great stability of form, Mr. Froude recommends that her period of oscillation should be made long, and the lengthening of the period can only be accomplished by two expedients—by raising the centres of all the weights to a great height above the water-line, so as to leave a small interval between the metacentre and the centre of gravity, and by removing all the weights far out from the middle of the ship, or winging the weights, as it is called. What I assert is, that such a cure is worse than the disease.

The evil which Mr. Froude fears, and to which he prescribes the antidote, is, the ship assuming a rapidly cumulative oscillation of great range. The example we have taken of a ship with a high metacentre and quick period, or what I call high stability of form, is one which would never deviate much from its former position, and would rapidly return to it. In such a case, the danger to be provided against does not exist—the danger which does exist, is of a totally different kind. It is to be feared, that such a ship will not turn quickly enough over the sharp crest of a wave on a high sea, and that it might therefore, instead of following gently over the top of the wave turn so slowly as to be overset, in the manner of Mr. Froude's thin plank. To raise the centre of weight in such a case, and make the turning motion still slower, is to increase the evil and bring the ship into real danger, and to wing the weights in such a case, is to make a ship whose danger would arise from not turning rapidly enough, still slower in its motions.

Having thus stated what I should not do, in order to make a ship wholesome and give her good sea-going qualities, I feel bound to say what I should do. I should take care not to give a ship a high metacentre, and not to give her great stability of form: in other words, the metacentre should not be raised higher above the water-line, than was absolutely required to carry the top weights and the press of sail intended. Still I should place the metacentre sufficiently high above the water to give her the degree of liveliness and quickness of movement necessary to enable her to turn the crest of the wave sufficiently quick to prevent the sea from coming on board and breaking over her. Next, I should place the centre of gravity either in, or below the water-line, just sufficiently far below the metacentre to give her, by weight, all the remainder of the quantity of stability necessary to make her carry her top weights, and stand up under her canvas.

What I think I should have accomplished by these arrangements, is as follows: by stability of form, I should have given her liveliness enough to enable her to move with

the water with sufficient rapidity to prevent her from taking in the sea over her side; and by bringing the centre of gravity just under the water-line, I should have prevented her from taking the too rapid motion, of a short, sharp, and quick sea. In like manner, instead of winging the weights in a heavy sea, to retard the period of oscillation, I should bring the weights nearer to the centre, and prevent the ship from labouring.

It will be seen from all this, that Mr. Froude and I wish to save the ship from opposite dangers. He fears the ship rolling herself over. I fear the sea breaking over the ship. To avert the evil he apprehends, he proposes to give the ship, at any cost, a period of long oscillation. I say that that, in many cases, even in most, would be to insure the loss of the ship from the evil which I most fear—the breaking crested sea of a storm. I think also that the dangers of the sea to a ship having already a high metacentre, would be greatly aggravated by giving to her also, a high centre of gravity. I believe in a low metacentre and a low centre of gravity for a wholesome ship.

I quite admit that a form of ship might be invented which would be extremely liable on wave water to the evil of cumulative oscillation. I do not think that is a common sort of ship. I even think it would be necessary to invent a shape on purpose; but what I would invent for practical purposes would be a shape as much the contrary of that as possible. A solid of revolution, all the parts of which from end to end resembled each other, and had a common axis of revolution, would be a capital rolling form. As contrary to this as possible would be, a ship with round elliptical or rectangular midship section, which should have very fine vertical ends in the water, and as different as possible from the shape of the middle. A form which I have much used, and which has shewn itself capable of withstanding for the longest period of time without injury, the severest action of the sea, and the heaviest rolling without taking in the sea, and, consequently, without dangerous accumulation, has been a flat floor, nearly upright sides, with round bilges of large radius. Going aft the shape becomes first a circle, then a triangle, and at last vertical deadwood aft, with a square counter aloft. And forward, the part in the water becoming a parallelogram, with a round bottom narrowing gradually to an upright stem, so that the whole now may be said to be bounded by vertical planes and to have extreme depth with extreme narrowness. It appears to me that with such a compound form, the accumulation of spontaneous oscillations is a sheer impossibility, and, therefore, to provide for it by ensuring a long period of oscillation, would be to waste the resources and expedients of the naval architect.

In conclusion I would say:—

First,—That standing up, under canvas, in still water, and standing up, under canvas, in wave water, are accomplished and measured in the same way.

Secondly,—That ships set to roll on smooth water will continue to roll in the same way relatively to the surface of wave water.

Thirdly,—That out of the combination of wave oscillation with ship oscillation, there would arise a cumulative action from synchronous oscillation.

Fourthly,—I do not think that this synchronism of oscillation is a formidable fact, or is an ordinary source of danger to real ships on real sea waves.

Fifthly,—I think that to provide against such a danger we ought not to encourage the building of a ship with a high metacentre, a high centre of gravity and a large radius of gyration.

Sixthly,—I should endeavour to provide against the dangers of the sea by a low metacentre, a centre of gravity not far below the water-line, and such a form of body accompanying the low metacentre as should be unfavourable to the commencement or the accumulation of long, slow oscillation of great range.

Seventhly,—I believe that there are elements in the oscillation of a ship more dangerous than that of synchronism with waves, and I believe that the nature of the forces which cause oscillations, produces varieties in the nature of the oscillations themselves very different, and much more important to the health of the ship than those which arise from the period of the oscillation merely ; and that these forces lie mainly in the shape of the ship, and that therefore two ships, with the same metacentric interval and period of oscillation, may be, the one a very dangerous, and the other a very wholesome ship.

I have still to notice that part of Mr. Froude's Paper, where he objects to my having followed Dr. Woolley in laying great stress on a certain conclusion enforced by Chapman. Our views, as he understands them, he states in the following sentence:— "When the form of a ship is such, that in heeling, the emergent solid differs widely in "bulk and form from the immergent, her rolling must be in a high degree jerky and "uneasy, in consequence of the rising and falling motion in the axis of the plane of "flotation which must accompany her oscillation."

So far as my understanding of the subject goes, the phrase "in consequence of" gives an entire misrepresentation both of the nature of the phenomena, and of my belief of the truth of the doctrine expressed in the remaining part of the paragraph. I do lay great stress on the conclusion, that when the form of the ship is such, that in heeling the emergent solid differs widely in bulk and form from the immergent, her rolling must be in a high degree jerky and uneasy; but I am far from thinking that the jerkiness and uneasiness of the motion is caused by the rising and falling motion in the axis of the plane of flotation.

What I do believe is, that the rising and falling motion, and the jerky and uneasy rolling are attendant phenomena—not cause and effect; and that both are the consequence of that malformation of the ship's body, which is alluded to.

I regret it is not possible to explain here, without writing an entirely new Paper, the various malignant characters which I have discovered in that kind of oscillation. The evil lies in quite another region of investigation from this, and all I can here say is, that the rising and falling motion in the axis of the plane of flotation is not even in the remotest degree the phenomenon which I deprecate, but only a subsidiary symptom of it. This short statement is, I hope, enough to shew that the difference of opinion which appeared to exist between Mr. Froude and myself, on this point, arises from his having attributed to me a form of expression which does not truly convey my meaning. My words were these:—"If, when the ship rolls on alternate sides, the part which goes into "the water and the part which comes out simultaneously, differ widely in form and bulk, "the movements of such a vessel are in a high degree jerky and uneasy."

It will be observed that I never said that the jerkiness and uneasiness consisted in, or was the consequence of the slight and comparatively gentle rising and falling of the centre of gravity, which is a secondary phenomenon merely.*

* Mr. Scott Russell's Postscript so very fairly throws back the weight of the discussion to which it refers, on the arguments already adduced on both sides, that it is needless, and would be indeed improper for me to add a word in the way of argumentative rejoinder. I have merely to say that without any wish to give an appearance of undue width to the difference between our views, I fear it is certainly wider than he believes it to be.

It will help to explain the grounds of my belief, if I point out that it will be found I have never restricted my theory of rolling to the behaviour of the thin plank to which he seems to regard them as restricted, but which I consider would less than almost any other form of floating body exemplify them. I regard them as emphatically applicable and appropriate to ships of such form as are in common use. And if the views I have adduced be true, they exhibit as the inevitable consequence of comparatively moderate, round-topped waves, injurious results, which, as it seems to me, Mr. Scott Russell's view altogether leaves out of sight—results, the general character of which, no local abruptness of waves can characteristically alter, though it may here and there mischievously intensify them.

It will further illustrate the nature of the difference between our views, if I point out that, while Mr. Scott Russell aims at, and says he can secure such a form of hull and such stowage as shall oblige the ship, always moderately, to raise her side to meet the approaching wave, so as to avoid the danger of a breaking sea coming on board of her, such a form is, in my view, practically impossible; and in my view, the danger to be apprehended in reference to the falling of a broken sea on board, is the irruption of the breaker during one of those weather rolls which must inevitably occur quasi periodically during the phases of the rolling of any ship, rendering the irruption serious in proportion as the conditions which govern those phases are such as to render the weather roll itself severe.

I have only, in conclusion, to thank the Council for the, perhaps, irregular concession which has enabled me to place side by side with Mr. S. Russell's Paper a written reply, which, from its length and its deliberateness, it would be absurd to regard as a mere expansion of the usual verbal reply during discussion. And especially, I have to thank Mr. Scott Russell for having so cordially concurred in the arrangement, and for having done everything in his power to enable me to bring my views into close juxtaposition, and if so be, contrast with his own. W. F.

POSTSCRIPT TO MR. FROUDE'S REMARKS ON MR. SCOTT RUSSELL'S PAPER ON ROLLING.

By Rev. Joseph Woolley, LL.D., Vice-President, I.N.A.

In a Paper which Mr. Froude has substituted for his verbal comments on Mr. Scott Russell's Paper on the Rolling of Ships, read on the 27th March, 1863, a great variety of new matter is opened up, interesting in itself and very fit to be brought before the Institute of Naval Architects. As my name has been alluded to, I may be permitted, as briefly as possible, to explain that part of my Paper read March 1st, 1860, to which Mr. Froude alludes.

I have had an opportunity of perusing Mr. Scott Russell's Postscript, and although I am not prepared at so short a notice to endorse all his remarks, I may safely aver that in the main I agree with them. I quite concur with him in his estimate of the value of Mr. Froude's investigations, and I greatly rejoice that the Institution of Naval Architects has already borne such valuable fruit as these and similar investigations by Mr. Froude and others, which are eminently calculated to advance the science of Naval Architecture, in a direction too, which has hitherto presented almost insuperable difficulties, and has consequently been little pursued. It is a great advantage that the attention of gentlemen possessing talents well suited to the discussion of those questions, and leisure to pursue them, has been arrested by, and directed into the right channels through, our Institution.

My only object, at present, is to explain how far Mr. Froude rightly interprets my meaning, when he states:—"The difference is now perhaps less marked in words, "yet scarcely less real, where Mr. Scott Russell, following Dr. Woolley, lays great "stress on a conclusion enforced by Chapman, that when the form of a ship is such, "that in heeling, the emergent solid differs widely in bulk and form from the "immergent, her rolling must be in a high degree jerky and uneasy, *in consequence of* "the rising and falling motion in the axis of the plane of flotation which must accom- "pany her oscillation." Which, Mr. Froude afterwards interprets as meaning "in "consequence of the rising and falling of the centre of gravity;" at least, it is on this peg that Mr. Froude hangs his investigations of the vertical oscillations of the centre of gravity.

In the Paper which I had the honor of reading on the first meeting of the Institution, it was my duty chiefly to give an outline of the conclusions to which others had arrived in the theory of naval architecture, although I did not shrink from advancing my own

opinions. Now, I was led to dwell on the fact of the rise and fall of the centre of gravity, because Canon Moseley, in his admirable *Memoir on the Dynamical Stability and Oscillation of Ships*, had been inadvertently led into the erroneous supposition that Dr. Inman and his pupils were unacquainted with this fact, which is inseparable from the ordinary form of ships and a position of the centre of gravity elsewhere than in the axis of rotation. I do not, myself, attach any special importance to the alternate rise and fall of this point, although, with Mr. Scott Russell, I do attach importance to a considerable change of the position of the axis of rotation during a vessel's heeling over; and this not from any superstitious belief in the properties of the surface of flotations, but rather in consequence of the state of things which is represented by large dimensions of that surface, *viz.*, the great inequality in the forms of the immergent and emergent solids. I think very good reasons could be shewn why this inequality, if great, should be accompanied by uneasiness of motion, and on the contrary, if reduced to insignificance, should be an index of easy rolling. As a matter of fact, those ships in the Royal Navy notorious for uneasy rolling, present in their forms remarkable examples of such inequality; while in the *Thetis*, and other vessels built by Messrs. Read, Chatfield, and Creuze, which are as celebrated for their peculiarly easy motion of rolling, one main feature in the construction was the reduction of this inequality to its lowest possible proportions. It is more proper to say, therefore, that the motion is uneasy when there is a great rising and falling of the axis of flotation, in consequence of the inequality between the immergent and emergent solids which it reveals, than the converse, which Mr. Froude attributes to me.

Those who were present at the discussion of the Paper of Mr. Scott Russell, cannot fail to have been struck by the wisdom of the concluding remarks of the Chairman, Canon Moseley, in which, while allowing fully the merit of the investigations of Mr. Froude, he bade naval architects be cautious in applying his conclusions, which are sufficiently in antagonism with all that have been heretofore formed with regard to the form which conduces to the best qualities in a sea-going ship. In these words of caution I fully concur, and for this reason, that Mr. Froude, in pressing the conclusions of his own theory, which is entitled to all respect, seems to forget that after all his mode of viewing the question is but one among several. He has satisfactorily established the fact that considerable danger may arise from too close a coincidence in the natural time of oscillation of a ship and the periodic time of the waves on which she is floating. With some limitations, such as are pointed out by Mr. Scott Russell, I am disposed to accept Mr. Froude's theory which leads to this conclusion, and to attribute very high value to it. On the other hand, there is nothing in Mr. Froude's theory which grapples with the question of the best form to be given to a ship in order to produce easy movements in still water at all. His theory assumes that the time of natural oscillation in a ship is

absolutely known, and is represented by the well-known formula $\frac{\pi k}{\sqrt{g \mathrm{G M}}}$; and that the behaviour of a ship in calm or storm depends on the *time* of oscillation so represented as the only element. It is here that, with Mr. Scott Russell, I am disposed to join issue with him. In the first place, this formula leaves out of account—except so far as it enters in some degree into the expression for the radius of gyration (k)—the whole form of the vessel between wind and water; and it would be easy to cite instances in which this formula would be equally true for vessels of very different shapes and known qualities. So long as a vessel may have the same area and form of plane of flotation, the same distance between centre of buoyancy and centre of gravity, and on the whole the same inertia, the time of oscillation and all the qualities as regards rolling are assumed to be the same whether the vessel flares out or tumbles home, or whatever peculiarity of form it may have given it about the water-line. This is the very error which Atwood took so much pains to correct nearly a century ago.

Again, as I stated in my Paper read in 1860, it is shewn by comparison of different models, used in verifying Canon Moseley's results at Portsmouth, in 1850, that the calculated dynamical stability differed in some forms from the experimental stability by no less than 32 per cent. This was due to the resistance of the fluid, which in many forms of vessel must be a most important element in considering the oscillation, both as regards extent and time, but is entirely left out in the formula on which alone Mr. Froude relies. Lastly, in the summary of Mr. Froude, and on which he recommends naval architects to adopt his novel principles of shipbuilding, no question arises beyond the comparison of the time of natural oscillation of the ship and the period of the waves. The *amplitude* of the oscillation, except as it enters into the formulæ which form the basis of the final comparison, is omitted from the enquiry, which omission cannot but lead to faulty results; and it is owing doubtless, to this cause, that Mr. Froude recommends a course which, if rigidly pursued, would in many cases lead the naval architect to give to his ship a form which would be so unstable as to render her liable to topple over almost in a single oscillation, without any further assistance from waves whose periodic times happen to coincide.

The limits which I have set myself do not permit my pursuing this subject further. I have only to remark, that it would be most dangerous to confound together those two distinct questions—First,—That of easy rolling and time of oscillation in still water; and secondly,—The effect of the waves in modifying the vessel's motion. With the latter of these Mr. Froude has to a great degree successfully grappled. The former has not, I think, received elucidation from his investigations, and yet it is at least as important as the other.

The CHAIRMAN (the Rev. Canon Moseley, M.A., F.R.S., Vice-President, I.N.A.): Mr. Froude calls upon us (as I understand his theory), to provide for ships being stable in rough water by building them so as to be unstable in smooth water. I do not wonder that Mr. Scott Russell should dispute the principles on which a conclusion such as this is founded. That fundamental principle by which the resultant of the pressures on a body floating on a wave, and to whatever depth sunk in it, is assumed by Mr. Froude to be that of a normal to the inclined surface of the wave, is indeed inconsistent with the well-known fact that a board loaded at one extremity floats not in a position perpendicular to the wave's side (as it would do if the pressures *under* the surface were normal to the surface), but almost *vertically*, whilst the normal direction of the *surface* pressures is shewn by the same board floating when *unloaded*, so that its surface is parallel to the sloping surface of the wave.

Perhaps I may be permitted to refer also to a difficulty in that general result of his theory which Mr. Froude has stated as follows:—"Though the effort of stability of any given ship depends primarily "on her mass, and the position of her metacentre and her centre of gravity, the rate at which she will "acquire or lose velocity, and the position she will assume at any period, may be wholly expressed in "terms of her periodic time"* (in still water). From this it follows, I think, that if two vessels having the same periodic times of rolling in still water were subjected to the action of the *same* wave, the rates at which they would acquire and lose velocity, and the positions they would assume at any period of the wave would be the *same*. But vessels may be constructed of dimensions however *different*, so as to have, nevertheless, equal periodic times of rolling in still water; for these times depend not on the weights of the vessels, or the *actual* dimensions of their parts, but on the *relative* weights and dimensions of those parts, independently of the total weights of the vessels. A very large and heavy, and a very small and light vessel, might therefore be built so as to have equal periodic times of rolling in still water. The difference of the dimensions of these vessels and of their weights might, indeed, be such that a wave which would scarcely disturb the one might be large enough to swamp the other, and yet, according to Mr. Froude's conclusion, they should roll exactly alike.

* *Transactions Institution Naval Architects*, Vol. II., page 192.

INTRODUCTION TO LLOYD'S REVISED RULES.

By Joseph H. Ritchie, Esq., Mem. Council, I.N.A.

Lloyd's Rules for the construction of ships have been so frequently brought before the Institution, and have been so much the subject of discussion among its members, that it has been thought desirable to annex to this Volume a revised code which was promulgated in 1863, with the intention of coming into force at the beginning of 1864.

This revised code of Rules has been formed with two objects, both of which have been much discussed in the Institution. The one is to carry into effect as far as possible a uniform system of construction which shall in all essential points secure strength of hull, wise disposition of material for economy, provisions for the safety of life and property, and durability. And this the new Rules accomplish in conformity with the generally established system of practice throughout the country.

The second object included in these Rules is to encourage and not to retard the introduction into naval architecture and shipbuilding of every real improvement in the mechanical structure of ships, that may better adapt them to the special object they may have in view. It had been often objected to the old Rules of Lloyd's, that they impeded the progress of the profession, by laying down invariable and inflexible rules for a mechanical art which was always in progress, and often making rapid strides in the path of improvement. This objection the new Rules entirely remove. They allow the classification of a ship of good material, of sound workmanship and of skilful design, to take rank according to her intrinsic qualities, in whatever manner those good qualities may have been achieved.

Under such circumstances, it is conceived that these Rules are entitled to a place in our *Transactions* as a record of sound legislation and professional progress.

Prior to the year 1854, there were no Rules for the Classification of Iron Ships. When in 1834 Lloyd's Register was published, there was not a single iron ship in it. But this new material for shipbuilding was silently making its way against existing natural prejudice, and iron was beginning to be used by some engineers and boiler-

makers, and a few shipbuilders, in the construction of sailing ships and steam vessels. The port of Liverpool deserves the credit of having taken the lead in this great innovation, which in thirty years has placed iron on a level with the material that had been used for shipbuilding in all countries for four thousand years.

And although iron is eight times heavier than water and ten times heavier than oak, yet from its being at the same time ten times stronger than oak, it has been proved, from the facility of uniting the parts together by welding or rivetting, that merchant ships can be constructed of greater general strength of iron than of oak, that they may be one-fifth lighter, thus leaving more displacement for carrying cargoes, that they will cost less originally, and that if the surfaces be carefully preserved from corrosion they can be kept up in good condition at less expense than wooden vessels; hence the rapid increase in their numbers. In the year 1838, the Committee of Lloyd's Register classed the first iron vessel that had ever been guaranteed as "fit for the safe "conveyance of dry and perishable cargoes." This barque was appropriately named the *Ironsides*; she was 271 tons register, was built at Liverpool, by Messrs. Jackson & Gordon, for Messrs. Cairns & Co. She was launched on 17th October, 1838, and was built of angle iron and plate iron, much in the same manner as iron ships are now built. She performed her first voyage to Rio de Janeiro and back without damaging any cargo. She was classed by the Committee of Lloyd's Register after careful consideration, on the 15th November, 1838, as "built of iron," with no letter. From this date until 1844 the Committee of the Register Book continued to class iron ships by the designation, "built of iron," but with no letter.

From 1844 till 1854 the Committee improved the classification by marking them A 1, "built of iron," but this character was limited to six years. However, before the termination of this six years' classification the number of iron ships had so increased, and the demands for some kind of higher class, based on admitted rules, was so general, that the Committee of Lloyd's Register considered it necessary to form a code of rules for their own guidance, and for that of the builders of iron ships; but having in vain solicited the assistance and concurrence of the iron shipbuilders throughout the country to form such rules, they in 1854 appointed a special committee, composed of the members of their Board most conversant with shipbuilding, who, with the assistance of their own surveyors (by collating the scantlings of iron ships already classed) compiled their celebrated Rules and Table of Scantlings for ships of six, nine, and twelve years' grade, and which, when confirmed by the General Committee, was prefaced as follows:—

> "Considering that iron shipbuilding is yet in its infancy, and that there are no well understood "general rules for building iron ships, the Committee have not deemed it desirable to frame a "scheme compelling the adoption of a particular form or mode of construction, but that certain

"general requirements should be put forward having for their basis thickness of plates and substance "of frame, shewing a *minimum in each particular* to entitle ships to the character *A* for a period of "years, subject however to certain periodical surveys; and also to a continuation of such character, "should their state and condition justify it on subsequent examination. For the purpose of attaining "this object the following Rules and the accompanying Table of Dimensions have been formed."

These Rules the Committee amended in 1857 by extending the room and space of the frames in twelve year ships from 16 inches to 18 inches, but increasing the thickness of the plating in all grades one-sixteenth of an inch throughout. And in 1861 the Rules and Tables of Scantlings were *limited* to vessels whose extreme length did *not* exceed *seven* times their extreme breadth, or *ten* times their depth of hold. At the time the Committee drew up the first Rules, in 1854, they felt that a classification of six, nine and twelve years, although it might approach the truth as to the probable comparative durability of the various kinds of timber of which such wooden ships were allowed by their Rules to be built, yet these characters could not correctly indicate the durability of vessels built of metal, which only deteriorated by the wasting of the surfaces, and whose durability depended on different laws from that of timber. But it was considered that these Rules of classing would serve until more experience was gained, not only on the durability of iron when subjected to the continued action of sea-water and the corrosive products of various cargoes, but also on unascertained points in the construction of iron ships which could not be premised from the most complete knowledge of wooden ships. And the result has been that the experience gained during the following nine years induced the Committee in 1863 to re-consider these Rules; and with this view they submitted certain preliminary suggestions on the subject to the now numerous iron shipbuilding establishments throughout the country, and to their own intelligent and experienced staff of surveyors. In reply they received valuable suggestions from twenty-four shipbuilding firms, and from twenty-eight surveyors, and these were in the first place referred to the two principal surveyors, Messrs. Martin and Ritchie, and their opinions having been modified and perfected by the Special Committee were finally reported on to the General Committee, who decided that the designation of class by *years* should be abolished and the monograms be for the future used in their places to designate the gradations of probable durability in such vessels, and indicate the length of time which might intervene between the special surveys upon which such vessels should retain their characters dependant on their continued efficiency. And in addition to this important change the rules for the construction of iron ships have been altered in the following particulars. The tonnage which is to regulate the strength of the various parts of the vessel is to be that *below* the *tonnage* deck *only*, and not to include the tonnage represented by a poop, or forecastle, or of a spar deck when intended for cabin accommodation alone. The skeleton of all ships, that is to say, the keel, stem,

sternpost, floors, frames, beams, keelsons, and stringers of the A A and A class are to be the same, but the thickness of the outside plating may be various.

The space of the frames in all grades is increased from 18 to 21 inches, and under certain conditions to 24 inches, and consequently the spacing of the beams is increased; and further to reduce the weight aloft, the plates of the beams, and the outside plating from the lower part of the sheer-strakes, to three-fifths the depth of holds above the upper side of keel, may be thinner; and also to relieve the ends of the ship from unnecessary weight, the floor plates and the outside plating aloft may be reduced for one quarter the length of the ship, forward and aft. The breadth of stringer plates is to be increased in proportion to the length of the vessel, and rules are added for increasing the strength of the sheer-strakes and beam stringers, and bilge keelsons, in ships *exceeding* in length *seven* times their breadth and *ten* times their depth. And it is now made requisite that the iron, of which all ships shall hereafter be built, must be capable of sustaining a tensile strain of 20 tons per inch. And to illustrate these Amended Rules the Committee resolved to publish with them engraved sketches of the various approved modes of constructing the several parts of iron ships.

It should be borne in mind that although the mode of constructing iron ships, primarily intended by these Rules, is the original and ordinary one of vertical frames and longitudinal plating, the Committee do not hesitate to admit into the Register Book, and into the same classes, vessels otherwise constructed if of equal strength; and have classed ships with longitudinal frames, or with diagonal frames, and many with double or cellular bottoms for water, ballast, &c.

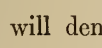
Having done so much for the hull of the vessel, the Committee have lately turned their energetic attention also to the equipment, and have out of their own funds, at considerable expense, established powerful testing machines in London, and have undertaken the supervision of others in the outports, and now require that all ships' anchors and chain cables shall be tested to the Admiralty proof.

And thus by wise and practical rules, administered with even-handed justice and impartiality, has this important Society striven to assist the shipbuilders and shipowners of this country to improve the merchant shipping of Great Britain and her Colonies, and are reaping a well-merited reward in the general improvement of the structure of iron ships, and in the increasing confidence reposed in them by all parties interested in shipping, having never had at any time so many vessels building in conformity to their Rules under the special supervision of their Surveyors, as at the present moment.

LLOYD'S REVISED RULES FOR THE BUILDING AND CLASSIFICATION OF IRON SHIPS—1863.

RULES FOR THE CLASSIFICATION OF SAILING AND STEAM VESSELS BUILT OF IRON.

ALL vessels will be classed A so long as on careful annual and periodical *special* surveys they are found to be in a fit and efficient condition to carry dry and perishable cargoes to and from all parts of the world.

Differences of construction, as regards thickness of plating, strength, and probable durability, &c., will be indicated by letters A, B, and C placed inside the letter A—thus,  .

will denote that the vessels have been built in accordance with, or equal to, the Rules and Table G.

will denote vessels which are considered entitled to the A character, but which have not been built in accordance with the Rules.

All vessels to be subject to occasional or annual survey when practicable.

To entitle ships to retain their respective characters in the Register Book, the following special surveys must be held periodically.

SURVEY No. 1.—The vessel to be placed on blocks of sufficient height in a dry dock, or on ways; the limber boards, and ceiling equal to *one* strake fore and aft on both sides removed, with both surfaces of outside plating exposed.*

SURVEY No. 2.—The vessel to be placed on blocks of sufficient height in a dry dock, or on ways; the limber boards, and ceiling equal to *three* strakes fore and aft on both sides removed, with both surfaces of outside plating exposed.*

SURVEY No. 3 BY TWO SURVEYORS, ONE TO BE AN EXCLUSIVE OFFICER OF THE SOCIETY.—The vessel to be placed on blocks of sufficient height, in a dry dock, or upon ways; proper stages to be made and the hold to be cleared, the close ceiling in the hold to be removed, so that the rivets and plates of keel, and flat of bottom, may be thoroughly examined; coal bunkers of steam vessels to be cleared, the whole of the frames, stringers, hooks, floor plates, keelsons, engine and boiler bearers, ends of beams, water-tight

* In cases where the inner surface of the bottom plating is coated with cement or asphalte, if a sufficient quantity of ceiling be removed to enable the coating to be carefully inspected, and tested by beating or chipping, and the coating be found sound and good and adhering satisfactorily to the iron, the removal of such coating will be dispensed with. Ships which have undergone the above examination will be noted in the Register Book thus (S.S.—) and if not submitted to such survey, will be liable to have their character suspended.

bulkheads, rivets, and inner surface of the plating exposed; all oxidation to be removed by being cut or beaten off the several parts above named, also from the outside plating, rivets, keel, stem, stern-post, and rudder, so as to completely lay bare all the surfaces of iron; the plank sheers and waterways, if of wood, to be scraped bright; and when the vessel is so prepared, the surveyors are to examine the condition and thickness of all the parts of iron above-named, also the condition of the plank sheers, waterways, flat of decks and their fastenings; such parts as may be found defective, or less than three-fourths of the required substance by rule, are to be removed and replaced with proper materials, equal in substance and quality to the original construction.

Whenever the bottom plating is to be cemented, a survey is to be held prior to the cement being laid.

Every ship classed ✠ must be submitted to a *special periodical survey* every *four* years:—the first survey according to No. 1; the second according to No. 2; the third according to No. 3; and afterwards according to No. 1 and No. 3 *alternately* at intervals of four years.

Every ship classed ✠B must be submitted to a special periodical survey every *three* years, as per No. 1, 2, and 3, afterwards No. 1 and 3.

Every ship classed ✠C must be submitted to a special periodical survey every *two* years, as per No. 1, 2, and 3, and afterwards No. 1 and 3.

RULES FOR THE BUILDING OF IRON SHIPS.

The scantlings given in Table G are intended for ships, the length of which, measured from the fore part of the stem to the after part of the stern-post, on the range of the upper deck, does not exceed seven times their breadth, or ten times their depth of hold, taken from the upper part of floors to the top of the upper deck beams. For ships which exceed in length ten times their depth, see Section 16.

Quality of Iron and Workmanship. Maker's Name.

1. The whole of the iron to be of good malleable quality, to be capable of bearing a longitudinal strain of twenty tons per square inch, and all plate, beam, and angle iron *to be legibly stamped in* TWO *places* with the manufacturer's trade mark, or his name and the place where made, which is also to be stated in the report of survey. The workmanship to be well executed, and submitted to the closest inspection before coating or painting: any brittle or inferior article to be rejected. (It is not intended to prevent the coating of the plates *inside* in the way of the frames.)

Keel, Stem, Stern, and Propeller Posts.

2. The keel, stem, stern, and propeller posts are to be either scarphed or welded together, and to be in size according to Table G; if scarphed, the length of scarphs to be eight times the thickness given in the table for keels; and the stern-posts and after end of keel, for screw propelled vessels, to be double the thickness of, or twice the sectional area of, the adjoining length of keel (but the siding in no case to be less than the thickness of the keel given in Table G), and to be tapered fair into the adjoining length of keel. Where the garboard strakes are thicker than required by the Rules, and extend to the bottom of the keel, the thickness of the keel may be proportionably reduced, but such reduction not to exceed one-third of the requisitions of the Rule. Where the keel and keelsons are made of several thicknesses of plates, the plates that form the keel to be in thickness, taken together, the same as is required for a solid keel, as per Table G; and the butts of the several plates of which the keel is formed to be carefully shifted from each other, and from the butts of the garboard strakes, which in all cases must also be shifted, so as

not to be opposite, or nearer each other than two spaces of frames. For thickness and breadth of hollow or flat plate keel, *see foot note of Table G.*

3. The frames to be of the dimensions set forth in Table G; to be in as great lengths as possible, fitted close on to the upper edge of the keel, and in all cases to extend to the gunwale; and when butted on the keel (except when double frames, or centre through plate keels, are adopted) and wherever elsewhere butted, to have not less than 4-feet lengths of corresponding angle iron fitted back to back to cover and support the butts and receive the plating. If welded together, the welds to be perfect, with not less than 4-feet shifts. Frames.

If single frames be adopted the space from centre to centre is not to exceed 21 inches all fore and aft; but provided an additional frame, for half the vessel's length amidships, be fitted at opposite sides of each floor plate, across the keel, and extended to upper part of bilges and rivetted through floor plates and main frames, also through the outside plating as required for main frames, the space may be increased to 23 inches in ships under 1,000 tons, and to 24 inches in ships of 1,000 tons and upwards. Spacing.

4. The floor plates to be in depth at middle line according to the following rule, *viz.*:—To the vessel's depth, measured from the top of keel to the top of upper or spar deck beams amidship, add the extreme breadth of the vessel; two-fifths of that sum *in inches*, to be the depth of the floor plates at middle line; their thickness to be as given in Table G; but at each end of the vessel, for one quarter of her length, they may be reduced in thickness one-sixteenth of an inch where the plates are less than ten-sixteenths, and two-sixteenths of an inch where the plates are ten-sixteenths and upwards. The floor plates to extend up the bilges to a perpendicular height of twice the depth of floors amidship from upper side of keel at middle line, and not to be less moulded at their heads than the moulding of the frames. A floor plate to be fitted and rivetted to every frame; and at the ends of the vessel, the floor plates to be worked across the middle line, so as to unite the sides of the vessel efficiently to each other. Watercourses are to be formed through all the floor plates on each side of middle line, so as to allow water to reach the pumps freely. Floor Plates. Watercourses.

5. Reversed angle iron on frames to be in size as per Table G. All vessels, of whatever size, to have reversed angle iron rivetted to every frame and floor plate across the middle line to the height of upper part of bilges, and to have double reversed angle iron in way of all keelsons and stringers in hold; and in addition, all vessels of 300 tons and upwards to have reversed angle iron extended from bilges to the upper deck beam stringer on *alternate* frames; and vessels of 800 tons and upwards to have reversed angle iron extended on *every* frame from bilges to above lower deck or hold beam stringer angle iron if the vessel has two decks or tiers of beams, and to above the height of middle deck beam stringer angle iron if the vessel has three decks or tiers of beams. The rivets for securing the reversed angle iron to the frames and floor plates to be in diameter equal to those specified in the Table for the outside plating, and not to exceed eight times their own diameter apart. Butts of reversed angle iron to be secured with butt straps. Reversed Angle Iron.

6. The middle line keelson, if of single plate, to be of the same thickness as the garboard strakes, and to be two-thirds of the depth of floor plates, and standing above the floor plates, and to be well fitted and rivetted thereto, and an angle iron of the size as per Table G, to be fitted on each side, both on the top and the bottom, extending all fore and aft; the lower angle irons to be rivetted to the double reversed angle irons on the top of floors. If a box keelson be adopted it is to be formed with a foundation plate, the plating to be of the thickness as per Table G, the depth not to be less than two-thirds of the depth of floor plates, and the breadth of the box two-thirds its depth. Middle Line Keelsons.

If an intercostal middle line keelson be adopted, it is to be of the same thickness as the floor plates, and rivetted to vertical angle iron on all floor plates at each end, the plates to extend from upper edge of keel to above the upper edge of floor plates, sufficiently high to be rivetted to bulb iron bars, of the same strength as the beams, or bars of other form, but of equal strength, between double angle irons, of the dimensions given in Table G, extending all fore and aft, and the said double angle irons of keelson are to be rivetted to double angle irons on top of all floor plates.

Where flat plate keels are used, the intercostal keelson plates to be fitted close down on and connected to the keel by double angle irons of the dimensions given in Table G, rivetted all fore and aft to the keel and keelson.

If the middle line keelson be formed of a centre through plate, extending from the lower edge of the keel to the top of the floors, it must not be less in thickness than that required in Table G for intercostal keelsons. To strengthen the floor plates transversely at their intersection at the middle line, in addition to the double vertical angle iron rivetted to their ends and to the centre plate keelson, there is to be a flat keelson plate, of the same thickness as the garboard strakes, and not less than three-fourths the breadth given in Table G, rivetted to double reverse angle irons on the upper edge of floors, and to two fore and aft angle irons on the upper edge of the centre through plate of the keelson. But should the centre through plate keelson be extended up above the upper edge of the floors, then it is to be rivetted by two fore and aft angle irons, of the size as per Table G, to two flat plates, one on each side of the middle line, to be well rivetted to the double reverse angle irons on the upper edge of the floors. In all cases the centre plate keelson to be extended to the stem and stern-post, and connected thereto where practicable.

Bilge Keelsons.

7. The bilge keelsons to be fitted and secured in an efficient manner, and to extend all fore and aft, and placed at lower turn of bilges, according to the form of the bottom. In ships of 1,000 tons and upwards, an intercostal keelson to be fitted on each side, as far forward and aft as practicable, and to be placed about midway between the middle line keelson and the bilge keelson, with double angle iron rivetted on the top of floor plates. All vessels of 500 tons and upwards to have fitted between the bilge keelsons and the hold beams, at the upper part of the turn of bilge, strong angle irons, as stringers, extending all fore and aft, rivetted back to back and to the reversed irons on the frames, the size of them not to be less than those used for the middle line keelson.

In all cases the middle line, side, and bilge keelsons, and *where practicable*, the stringers are to be carried fore and aft, without being cut off at the bulkheads, the latter being made watertight around them; and where such parts of the ship are necessarily separated, the longitudinal strength to be efficiently maintained to the satisfaction of the Surveyor.

Plating.

8. No plates to be less in length than five spaces of frames, except the fore and after hoods. No butts of outside plating in adjoining strakes to be nearer each other than two spaces of frames. In vessels under 1,200 tons, the plating may be reduced from the thickness shewn in Table G, one-sixteenth of an inch forward and aft, for a distance not exceeding one quarter of the length of the vessel from each end, below the upper edge of main sheer-strake, down to a perpendicular height from upper side of keel of three-fifths the internal depth of hold; and in ships of 1,200 tons and upwards a reduction of two-sixteenths will be allowed; the plates next abaft and next afore the quarter length of the vessel, to be of an intermediate or graduated thickness, between that required in midship and the reduction allowed at the ends.

In screw-propelled vessels, however, no reduction is to be made in the plating at the after end, below the lower part of the rudder trunk.

All plates are to be well fitted, and secured to the frames and to each other; the butts to be closely fitted, by planing or otherwise, and to be united by butt straps, of not less than the same thickness as the plates, and of sufficient breadth for rivetting, as described hereafter, and to be fitted with the fibre of the iron in the same direction as the fibre of the plates to which they are rivetted; the space between the plating and the frames to have solid filling or lining pieces, closely fitted in one length, and of the same breadth as the frames. Butt Straps.

It is recommended that in all cases the sheer-strake be an outside strake, so as to admit of the butt straps or lining pieces being extended, in one piece, from the foreside of the frame next afore the butts to the aftside of the frame next abaft the butts, or to admit of doubling the sheer-strake where it may be required.—*For breadth of sheer-strake see foot note in Table G.*

9. In raised quarter decks, a reduction of one-fifth from the thickness required by the Table G for such parts in the range of the upper deck in ships with two decks will be allowed in the outside plating, beams, stringer plates upon beams, angle iron on stringer plates, and flat of deck. Reductions allowed in raised Quarter Decks.

In full poops and top-gallant forecastles a reduction of one-fourth from the thickness required by the Table G for such parts in the range of the upper deck in ships with two decks will be allowed in the outside plating, stringer plates upon beams, angle iron on stringer plates and flat of deck, but in no case need the outside plating exceed $\frac{6}{16}$ in thickness. The united lengths of poop and forecastle not to exceed three-fifths of the entire length of the upper deck. Poop, Forecastles, &c.

In vessels with three decks (*viz.*, upper, middle, and lower deck), a reduction of one-sixth from the dimensions given for such parts in the range of upper deck in ships with two decks will be allowed in the scantling of beams, plating, flat of deck, stringer plates, and angle iron on stringers to upper deck. Three-decked Ships.

For vessels having three decks or tiers of beams, where the space under the upper one of which is intended only to be fitted as a "spar deck" for cabin accommodation, and above which there is no accommodation for crew or passengers, or where this spar deck is intended to enclose the engine openings of steam vessels, also in all vessels having poops and forecastles, the gross register tonnage below the "tonnage deck" (that is to say, below the middle deck in spar-decked ships, or the upper deck in poop-deck ships) is to regulate all scantlings below this deck, *except the depth of floor plates and the number of keelsons, and depth of hold for limiting thickness of outside plating.* The measurement of raised quarter decks is to be included in the gross tonnage. But no upper deck is to be considered a "spar deck" unless the total depth of hold of the vessel exceeds three-fourths of the extreme breadth; and in the arrangements of strength in proportion of length to depth, the height of the "tonnage" or middle deck from the top of the floor plates is to be taken as the depth for such purpose. In such spar decks or poops, or forecastles, there may be a diminution of one-fourth in the sizes and thickness of all beams, plating, stringers, and flat of deck, from that shewn in Table G; but all frames are to extend to the stringer plates of the spar deck, poop, or forecastle. Spar Deck.

Every vessel taking advantage of this Rule, as regards an entire spar deck, will be noted in the Register Book thus:—"*Spar decked.*"

For Equipment, the *gross register tonnage* is to be taken, except for anchors and cables for Steam-vessels.

10. Beam plates to be in depth $\frac{1}{4}$ of an inch for every foot in length of the midship beams, and to Beams.

be in thickness $\frac{1}{16}$ of an inch for every inch in depth of the said beams, and to be made of T bulb iron, or bulb plate with double angle irons rivetted on upper edge; the two sides of each of these angle irons to be not less in breadth than $\frac{3}{4}$ the depth of beam plate, and to be in thickness $\frac{1}{16}$ of an inch for every inch of the two sides of the angle iron; where beams below the upper or middle deck (including orlop beams) have no deck laid upon them, the angle irons on their upper edges to be of the dimensions required for the angle iron of the reverse frames; or the beams may be composed of any other approved form of beam iron, equal to the strength herein required. All beams to be well and efficiently connected or rivetted to the corresponding frames, at the sides of the vessel, with bracket ends or knee plates; each arm of knee plates at ends of beams not to be less in length than twice and half the depth of beams, and to be in thickness equal to the beams. The beams of each deck to be placed over each other, and pillared where practicable.

Upper deck beams in vessels with one or two tiers of beams, and the upper (or spar deck) and middle deck beams in vessels with three tiers of beams, to be fastened to alternate frames.

Vessels of 12 feet and under 13 feet depth of hold, or where the gross register tonnage exceeds 200 tons, shall be required to have as many hold beams as may be practicable or convenient, fastened to at least every eighth frame. Vessels not being of a depth to require hold beams are to have a double angle iron stringer rivetted to reverse frames extending all fore and aft about midway between bilge keelson and deck beams.

Vessels of 13 feet depth and under 15 feet, to have hold beams fastened to every fourth frame.

Vessels of 15 feet depth and under 18 feet, to have hold or lower deck beams fastened to every second and fourth frame, alternately.

Vessels of 18 feet depth and above, to have hold or lower deck beams fastened to every alternate frame, and the same number of middle-deck beams, where such are required.

All vessels having two decks (*viz.*, upper and lower deck), and exceeding 24 feet in depth from the top of floor plates to the upper side of upper deck beams, and vessels with three decks (*viz.*, upper, middle, and lower deck), and exceeding 24 feet in depth to the upper side of middle deck beams, and where the depth from under side of lower deck beams exceeds 15 feet, such ships to have orlop beams fastened to every sixth frame; also to have stringer plates and angle iron on their ends, all fore and aft, *equal in strength to* the requirement at Section No. 15; but, in the case of flush-deck ships, a depth of 25 feet will be allowed, provided the lower hold does not exceed 16 feet in depth from the under side of lower-deck beams. Should a house be constructed on such flush-deck ship for lodging crew or for store room, the same not to extend within 10 feet of the stern-post.

When the spaces between beams exceed two spaces of frames, a knee or bracket plate is to be rivetted to alternate frames and to the stringer plate at underside.

Depth of Hold for Space of Beams.

For the arrangement of beams the depth of hold is to be measured amidship from the top of the floor plates to the top of the upper-deck beams in vessels with two decks, and to the top of the middle-deck beams in vessels with three decks.

Where a deviation from the foregoing Rules as applying to beams takes place in way of engine rooms or hatchways, or where no deck is intended to be laid, and the above named spaces would materially interfere with the stowage of cargo, and where partial or entire bulkheads with horizontal stringers between them, or larger beams are substituted for ordinary beams in wider spaces, a sketch with all particulars must

be submitted through the resident surveyor, for the Committee's consideration. The middle deck to be a perfect deck laid and caulked.

Rivets and Rivetting.

11. The rivets to be of the best quality, and to be in diameter as per Table G; the rivet holes to be regularly and equally spaced and carefully punched opposite each other from the faying surfaces in the laps and lining pieces or butt straps, and to be countersunk all through the outer plating; the rivets not to be nearer to the butts or edges of the plating, lining pieces to butts, or of any angle iron, than a space not less than their own diameter, and not to be further apart from each other than four times their diameter, or nearer than three times their diameter, and to be spaced through the frames and outside plating, and in reversed angle iron, a distance equal to eight times their diameter apart. When rivetted up they are completely to fill the holes, and their points or outer ends are to be round or convex, and not to be below the surface of the plating through which they are rivetted. All vessels to have all edges or horizontal joints of outside plating double rivetted from the keel to the height of upper part of bilges, all fore and aft; but vessels of 700 *tons and above*, intended for the highest grade, are to have all edges or horizontal joints of outside plating double rivetted throughout. The stem, stern-post, keel, edges of garboard strakes and sheer-strakes, and butts of outside plating, and butts of floor plates, breasthooks, transoms, and plates of beams, also butts of keelsons, stringers, shelf-plates, and all longitudinal ties, to be double rivetted in all vessels. The overlaps of plating, where double rivetting is required, not to be less than five and a half times the diameter of the rivets; and where single rivetting is admitted, to be not less than three and a quarter times the diameter of the rivets. If double rivetting be adopted where single rivetting is allowed by the Rules, the diameter of the rivets may be reduced one sixteenth of an inch below that prescribed by the Rules, provided that in no case the diameter be less than five-eighths of an inch. The butts and edges of outside plating to be truly fitted, carefully caulked, and made water-tight.

Bulkheads.

12. Steamers, in addition to the engine-room bulkheads, to have two water-tight bulkheads built at a reasonable distance from the ends, to extend from the keel and outside plating to the upper deck in vessels with two decks, and to the middle deck in vessels with three decks (otherwise called "tonnage deck"); but the aftermost bulkhead will not be required to extend to this height if it be continued above the load water line, and be connected to a water-tight platform or deck of iron extending from its upper part entirely round the after part of the vessel, thus rendering the lower after body a water-tight compartment. The bulkhead is to be made water-tight where a screw-shaft passes through. In sailing ships, the foremost or collision bulkhead only will be required. All plating of bulkheads to be of the thickness prescribed in Table G; and when fitted between two frames at each side of the vessel, to be strongly rivetted through them; or if attached only to one frame, then to have brackets or knee plates rivetted horizontally against the side plating of the vessel and to the bulkheads, forcside and afterside alternately, near the middle of the outside plates, and to be strongly rivetted thereto. Lining pieces between these frames and outside plating in way of bulkheads, are to be plates extending in one piece from the forcside of the frame afore, to the aftside of the frame abaft the bulkhead frames. The bulkheads to be supported vertically by angle irons (of the dimensions given in Table G) not exceeding 2 feet 6 inches apart; and to be efficiently connected and rivetted together and to the corresponding floors, beams of the several decks, and the frames. All such bulkheads to be caulked and be made thoroughly water-tight. Where a pump is not fitted in each compartment, a sluice, cock, or valve is to be fitted at the limbers on each side of middle line, at each water-tight bulkhead, so as to allow water to be shut off, or to reach the pumps when required; the same to be worked from the deck above.

Ceiling.

13. The wood ceiling or lining of all vessels to be from $1\frac{1}{2}$ inches to 3 inches in thickness, in proportion to the tonnage, and to be so fastened to the reversed angle irons or frames that it may be easily removed for survey and painting.

Decks, Waterways, and Plankshеers.

14. The flat of upper deck to be fastened by screw bolts from the upper side, with nuts at the under side of the angle iron of the beams; where the planks exceed 6 inches in width there must be two bolts in each plank in every beam, one of which may be a short screw bolt, provided the planks do not exceed 8 inches in width, in which case both bolts must be put through. The water-ways, if of wood, to be fastened with screw bolts with nuts at under side of stringer plates.

Stringers.

15. All vessels to have stringer plates (of the thickness given in Table G) upon the ends of each tier of beams. Those upon the ends of upper deck beams in vessels with two decks or tiers of beams, and on ends of middle deck beams in vessels with three decks or tiers of beam, to be in width 1 inch for every 7 feet of the vessel's entire length, for half her length amidships, and from thence to the ends of the vessel they may be gradually reduced to three-fourths the width amidship—in no case, however, is the width to be less than 18 inches amidship. The stringer plates are to be fitted home and rivetted to the outside plating at all upper decks, and at the middle deck in vessels having three decks, with angle iron of the dimensions given in Table G: the middle deck stringer plate to have an additional angle iron extending all fore and aft inside of the frames rivetted to the reverse angle iron on the frames, and to the stringer plate. Stringer plates on ends of beams below the upper deck in vessels with two decks, or below middle deck in vessels with three decks, may be reduced in width to three-fourths the midship breadth above named, this breadth is to be extended all fore and aft, and to have an angle iron of the dimensions given in Table G, extending all fore and aft, rivetted to the reverse angle iron on the frames, and to the stringer plates. In cases where no deck is laid, and the width of stringer plate on ends of hold beams is objected to, it may be reduced, provided such reduction be fully compensated for. The objectionable practice of cutting through the stringer plates for the admission of wood roughtree stanchions will not be allowed.

Tie plates.

All vessels are to have tie-plates ranging all fore and aft upon each tier of beams on each side of hatchways, and wherever practicable from side to side diagonally, to be in width one and a half the depth of beams, and of the thickness required for stringer plates. The said plates are to be well rivetted to each other, and to beams, deck hooks, and transoms; and all butts to be properly shifted. Upon hold beams where no deck is to be laid, or where tie plates would interfere with stowage of cargo, an angle iron of the dimensions given in Table G for angle iron on beam stringers, placed at middle line, extending fore and aft where practicable, and well rivetted to all beams, deck hooks, and transoms, will be admitted in lieu thereof.

16. In the following cases the additional longitudinal strength beyond that stated in Table G will be required, *viz*:—

Ships above 10 depths.

Ships above 10, and not exceeding 11 depths in length, to have the main sheer-strake increased in thickness one-sixteenth of an inch amidships, for three-fourths the length of ship; or to have a doubling strake not less than 9 inches broad, for the same distance amidships.

Ships above 11 depths.

Ships above 11, and not exceeding 12 depths in length, to have the main sheer-strake increased in thickness two-sixteenths of an inch amidships, for three-fourths the length of ship, or to have a doubling strake not less than 12 inches broad, for the same distance amidships.

Ships above 12, and not exceeding 13 depths in length, to have the main sheer-strake increased in thickness two-sixteenths of an inch amidships, for three-fourths the length of ship, or to have a doubling strake not less than 18 inches broad, for the same distance amidships; and the stringer plate upon ends of upper deck beams, in vessels with two decks, or on ends of middle deck beams, in vessels with three decks, is to be increased two-sixteenths of an inch in thickness for half the ship's length amidships, or to be proportionately increased in width for the same distance, and to have a bulb plate of the dimensions required for beam plates, placed between and rivetted to the double angle iron keelson, at lower part of bilges, for half the length of the ship amidships. Ships above 12 depths.

In all the above cases, the doubling plate is not to be of less thickness than the strake next below the sheer-strake, and fitted at the upper edge of the sheer-strake.

In ships above thirteen, and not exceeding fourteen depths in length, the main sheer-strake to be doubled its entire breadth for three-fourths the length of ship amidships, the doubling is not to be of less thickness than the strake next below the sheer-strake and fitted upon the edge of the same, and to extend in one or two breadths of plating to the upper edge of sheer-strake. The stringer plate on ends of beams and the bulb plate between the angle irons at bilges to be as is required in the preceding case. Ships above 13 depths.

In cases of ships which exceed fourteen depths in length, the builders are to submit to the Committee, through the resident surveyor, their plans for giving the vessel sufficient additional strength longitudinally. Ships above 14 depths.

17. The main piece of rudder to be in size according to Table G, of the best hammered iron, and the plating to be carefully stayed and rivetted. Rudder.

18. Vessels intended for classification to be surveyed as follows, *viz*:— Surveys.

1*st*. On the several parts of the frame, when in place, and before the plating is wrought.

2*nd*. On the plating during the progress of rivetting.

3*rd*. When the beams are in and fastened, and before the decks are laid.

4*th*. When the ship is complete, but before the plating is finally coated or cemented.

5*th*. And lastly, after the ship is launched and equipped.

For Equipments, see Sections, 71, 72, 73, 74, 75 and 76, of Wood Ships.

SHIPS NOT BUILT UNDER SURVEY.

19. In cases of ships not surveyed while building for which a character may be required, application must be made to the Committee in writing, who will direct a special examination to be made by two Surveyors of the Society (one of whom shall be an exclusive officer), for which purpose the vessel is to be placed on high blocks in a dry dock or upon ways; the hold to be cleared and proper stages made; the rivets and plating of keel, and flat of bottom thoroughly examined; the close ceiling in the hold to be removed, and coal bunkers of steam vessels to be cleared; the whole of the frames, stringers, hooks, floor plates, keelsons, engine and boiler bearers, ends of beams, water-tight bulkheads, rivets, and inner surface of the plating exposed to view; all oxidation to be removed by being cut or beaten off the several parts above named, also from the outside plating, rivets, keel, stem, stern-post, and rudder, so as to completely lay bare all the surfaces of iron; the planksheers and waterways, if of wood, to be scraped bright: and when the vessel is so prepared, the Surveyors are to examine the condition and thickness of all the parts

of iron above named, also the condition of the planksheers, waterways, flat of decks and their fastenings; and send a detailed report thereon, and on the dimensions and quality of the materials and workmanship to the Committee, who will then assign the vessel such character as the facts may appear to them to warrant, and define the periodical Surveys to which they shall respectively be subjected.

By order of the Commitee,

GEORGE B. SEYFANG,

Secretary.

2, White Lion Court, Cornhill, London,
18*th June*, 1863.

Mem.—The foregoing Rules have been framed for iron ships built with vertical frames and longitudinal plating. Parties desirous of constructing vessels varying from the Rules, must submit their plans with specifications, for approval.

Hollow or flat keel plates and garboard strakes, and main sheerstrakes, are not to be less in breadth than as follows, ships under 500 tons, 2 ft.; in ships 500 and under 1,000 tons, 2 ft. 6 in; in ships 1,000 tons and upwards, 3 ft. When flat plate keels are adopted, their thickness should not be less than one and a half that of the garboard strake.—*For her forms, see Section* 2.

GROSS TONNAGE.	K a p c
100 and under 200	6
200 and under 300	6¼
300 and under 400	6½
400 and under 500	6¾
500 and under 600	7
600 and under 700	7
700 and under 800	7¼
800 and under 900	7½
900 and under 1,000	8
1,000 and under 1,200	8½
1,200 and under 1,500	9
1,500 and under 2,000	10
2,000 and under 2,500	12
2,500 and under 3,000	12
3,000 and under 3,500	12

Mem.—Th
times their extren

Diam
Thick

Floor Plates.—The floor plates to be in depth at middle line according to the following rule, *viz:*—To the vessel's asured from the top of keel to the top of upper or spar deck beams amidships, add the extreme breadth of the vessel; of that sum *in inches*, to be the depth of the floor plates at middle line; their thickness to be as given in Table; but d of the vessel, for one-quarter of her length, they may be reduced in thickness one-sixteenth of an inch where the less than ten-sixteenths, and two-sixteenths of an inch where the plates are ten-sixteenths and upwards. The floor xtend up the bilges to a perpendicular height of twice the depth of floors amidships from upper side of keel at , and not to be less moulded at their heads than the moulding of the frames. A floor plate to be fitted and rivetted ame; and at the ends of the vessel, the floor plates to be worked across the middle line, so as to unite the sides of efficiently to each other. Watercourses are to be formed through all the floor plates on each side of middle line, so water to reach the pumps freely.

Plating.—No plates to be less in length than five spaces of frames, except the fore and after hoods. No butts of ting in adjoining strakes to be nearer each other than two spaces of frames. In vessels under 1,200 tons the y be reduced from the thickness shewn in table, one-sixteenth of an inch forward and aft, for a distance not one-quarter of the length of the vessel from each end, below the upper edge of main sheerstrake, down to a lar height from upper side of keel of three-fifths the internal depth of hold; and in ships of 1,200 tons and upwards, of two-sixteenths will be allowed; the plates next abaft and next afore the quarter length of the vessel, to be of diate or graduated thickness, between that required amidships and the reduction allowed at the ends. In screw-essels, however, no reduction is to be made in the plating at the after end, below the lower part of the rudder trunk.

T Straps.—All plates are to be well fitted, and secured to the frames and to each other; the butts to be closely laning or otherwise, and to be united by butt straps, of not less than the same thickness as the plates, and of breadth for rivetting, as described hereafter, and to be fitted with the fibre of the iron in the same direction as the plates to which they are rivetted; the space between the plating and the frames to have solid filling or lining pieces, ed in one length, and of the same breadth as the frames. It is recommended that in all cases the sheerstrake be an ake, so as to admit of the butt straps or lining pieces being extended, in one piece, from the foreside of the frame the butts to the aftside of the frame next abaft the butts, or to admit of doubling the sheerstrake where it may be *For breadth of sheerstrake see foot note above.*

Beams.—Beam plates to be in depth one quarter of an inch for every foot in length of the midship beams, and to be ss one-sixteenth of an inch for every inch in depth of the said beams, and to be made of T bulb iron, or bulb plate, e angle irons rivetted on upper edge; the two sides of each of these angle irons to be not less in breadth than three- depth of beam plate, and to be in thickness one-sixteenth of an inch for every inch of the two sides of the angle e beams below the upper or middle deck (including orlop beams) have no deck laid upon them, the angle irons on edges to be of the dimensions required for the angle iron of the reverse frames; or the beams may be composed er approved form of beam iron, equal to the strength herein required. All beams to be well and efficiently connected to the corresponding frames, at the sides of the vessel, with bracket ends or knee-plates; each arm of knee plates beams not to be less in length than twice and a half the depth of beams, and to be in thickness equal to the beams. of each deck to be placed over each other, and pillared where practicable.

Stringer and Tie-plates.—All vessels to have stringer plates (of the thickness given in Table), upon the ends of f beams. Those upon the ends of upper deck beams in vessels with two decks or tiers of beams, and on ends of k beams in vessels with three decks or tiers of beams, to be in width one inch for every seven feet of the vessel's gth, for half her length amidships, and from thence to the ends of the vessel they may be gradually reduced to his the width amidships—in no case, however, is the width to be less than eighteen inches amidships. The stringer to be fitted home and rivetted to the outside plating at all upper decks, and at the middle deck in vessels having s, with angle iron of the dimensions given in Table: the middle deck stringer plate to have an additional angle ling all fore and aft inside of the frames, rivetted to the reverse angle iron on the frames, and to the stringer plate. ates on ends of beams below the upper deck in vessels with two decks, or below middle deck in vessels with three be reduced in width to three-fourths the midship breadth above named, this breadth is to be extended all fore and aft ve an angle iron of the dimensions given in Table, extending all fore and aft, rivetted to the reverse angle iron on , and to the stringer plates. In cases where no deck is laid, and the width of stringer plate on ends of hold beams to, it may be reduced, provided such reduction be fully compensated for. The objectionable practice of cutting e stringer plates for the admission of wood roughtree stanchions will not be allowed. All vessels are to have tie- ging all fore and aft upon each tier of beams on each side of hatchways, and wherever practicable from side to side , to be in width one and a half the depth of beams, and of the thickness required for stringer plates. The said to be well rivetted to each other, and to beams, deck hooks, and transoms; and all butts to be properly shifted. beams where no deck is to be laid, or where tie-plates would interfere with the stowage of cargo, an angle iron of the s given in Table for angle iron on beam stringers, placed at middle line, extending fore and aft where practicable, ivetted to all beams, deck hooks, and transoms, will be admitted in lieu thereof.

Rivets and Rivetting.—The rivets to be of the best quality, and to be in diameter as per Table; the rivet holes to be nd equally spaced and carefully punched opposite each other from the faying surfaces, in the laps and lining pieces aps; and to be countersunk all through the outer plating; the rivets not to be nearer to the butts, or edges of the ning pieces to butts, or of any angle iron, than a space not less than their own diameter, and not to be further apart other than four times their diameter, or nearer than three times their diameter, and to be spaced through the frames e plating, and in reversed angle iron, a distance equal to eight times their diameter apart. When rivetted up they tely to fill the holes, and their points or outer ends are to be round or convex, and not to be below the surface of g through which they are rivetted. All vessels to have all edges or horizontal joints of outside plating double m the keel to the height of upper part of bilges, all fore and aft; but vessels of 700 *tons and above*, intended for the ade, are to have all edges or horizontal joints of outside plating double rivetted *throughout*. The stem, stern-post, s of garboard strakes and sheerstrakes, and butts of outside plating, and butts of floor plates, breasthooks, and plates of beams, also butts of keelsons, stringers, shelf plates, and all longitudinal ties, to be double rivetted in The overlap of plating, where double rivetting is required, not to be less than five and a half times the diameter ts; and where single rivetting is admitted, to be not less in breadth than three and a quarter times the diameter of If double rivetting be adopted where single rivetting is allowed by the Rules, the diameter of the rivets may be e-sixteenth of an inch below that prescribed by the Rules, provided that in no case the diameter be less than five- an inch. The butts and edges of outside plating to be truly fitted, carefully caulked, and made water-tight.

TABLE G.

IRON SHIPS.—TABLE OF MINIMUM DIMENSIONS OF FRAMES, PLATING, RIVETS, KEELS, KEELSONS, STEMS, STERN POSTS, FLOOR PLATES, BEAMS,‡ BULKHEADS, STRINGERS, &c.

All plates, and all beam and angle iron, used in Ships intended for classification, are to be stamped legibly in two places with the manufacturer's trade mark, or his name and the place where made.

GROSS TONNAGE	Keel, Stem, and Stern Post for all Grades.*	Distance of Frames from Moulding edge to Moulding edge all fore and aft for all Grades.	FRAMES. Dimensions of Angle Iron for all Grades.	Dimensions of Reversed Angle Iron on Frames, Bulkheads and Box Keelsons for all Grades.	THICKNESS OF OUTSIDE PLATES.† Garboard Strakes* and Single Plate Middle Line Keelsons standing upon Floors. A	Garboard Strakes* and Single Plate Middle Line Keelsons standing upon Floors. B	From the Garboard to the upper part of Bilge, and the Sheerstrakes.* A	From the Garboard to the upper part of Bilge, and the Sheerstrakes.* B	From upper part of Bilge to a perpendicular height from upper side of Keel of 3-5ths the internal depth of Hold. A	From upper part of Bilge to a perpendicular height from upper side of Keel of 3-5ths the internal depth of Hold. B	From three-fifths the depth of Hold to lower edge of Sheerstrake. A	From three-fifths the depth of Hold to lower edge of Sheerstrake. B	‡ Thickness of Stringer plates upon Beams, Floor plates, Hooks, Crutches, & Box, or Intercostal Keelsons for all grades.	Thickness of Plates for Bulkheads for all Grades.	Dimensions of Angle Iron or Beam Stringers or Keelsons for all Grades.	RUDDER for all Grades. Diameter at the Head.	RUDDER for all Grades. Diameter at the Heel.	Thickness of Wood Flat of Upper Deck.	GROSS TONNAGE.
	Inches.	If single frames be adopted the space from centre to centre is not to exceed 21 inches, all fore and aft; but provided an additional frame, for half the vessel's length amidships, be fitted at opposite side of each floor plate across the keel, and extended to upper part of bilges, and riveted through floor plates and main frames, also through the outside plating, as required for main frames, the spaces may be increased to 23 inches in ships under 1,000 tons, and to 24 inches in ships of 1,000 tons and upwards.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	
100 and under 200	$6\times1\frac{1}{2}$		$\frac{6}{16}\times2\frac{1}{2}\times2\frac{1}{2}$	$\frac{5}{16}\times2\frac{1}{4}\times2\frac{1}{4}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{6}{16}$	$\frac{6}{16}$	$\frac{5}{16}$	$\frac{6}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{4}{16}$	$\frac{6}{16}\times3\times3$	3	2	$2\frac{1}{2}$	100 and under 200
200 and under 300	$6\frac{1}{4}\times2$		$\frac{6}{16}\times3\times2\frac{1}{2}$	$\frac{5}{16}\times2\frac{1}{4}\times2\frac{1}{4}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{6}{16}$	$\frac{6}{16}$	$\frac{5}{16}$	$\frac{6}{16}$	$\frac{4}{16}$	$\frac{6}{16}\times3\times3$	$3\frac{1}{2}$	2	$2\frac{1}{2}$	200 and under 300
300 and under 400	$6\frac{1}{2}\times2\frac{1}{4}$		$\frac{6}{16}\times3\frac{1}{4}\times2\frac{3}{4}$	$\frac{5}{16}\times2\frac{1}{2}\times2\frac{1}{2}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{6}{16}$	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{6}{16}\times3\frac{1}{2}\times3$	$3\frac{3}{4}$	$2\frac{1}{4}$	3	300 and under 400
400 and under 500	$6\frac{3}{4}\times2\frac{1}{2}$		$\frac{7}{16}\times3\frac{1}{2}\times2\frac{3}{4}$	$\frac{6}{16}\times2\frac{3}{4}\times2\frac{1}{2}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{6}{16}$	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{6}{16}\times4\times3$	$4\frac{1}{4}$	$2\frac{1}{2}$	3	400 and under 500
500 and under 600	$7\times2\frac{1}{2}$		$\frac{7}{16}\times3\frac{3}{4}\times2\frac{3}{4}$	$\frac{6}{16}\times3\times2\frac{1}{2}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{8}{16}$	$\frac{6}{16}$	$\frac{7}{16}\times4\frac{1}{4}\times3\frac{1}{4}$	$4\frac{1}{2}$	$2\frac{3}{4}$	$3\frac{1}{2}$	500 and under 600
600 and under 700	$7\times2\frac{3}{4}$		$\frac{7}{16}\times4\times3$	$\frac{6}{16}\times3\times2\frac{3}{4}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{8}{16}$	$\frac{6}{16}$	$\frac{7}{16}\times4\frac{1}{2}\times3\frac{1}{2}$	$4\frac{3}{4}$	$2\frac{3}{4}$	$3\frac{1}{2}$	600 and under 700
700 and under 800	$7\frac{1}{4}\times2\frac{3}{4}$		$\frac{8}{16}\times4\frac{1}{4}\times3$	$\frac{7}{16}\times3\times2\frac{3}{4}$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{9}{16}$	$\frac{6}{16}$	$\frac{8}{16}\times4\frac{3}{4}\times3\frac{1}{4}$	5	3	$3\frac{1}{2}$	700 and under 800
800 and under 900	$7\frac{1}{2}\times3$		$\frac{8}{16}\times4\frac{1}{2}\times3$	$\frac{7}{16}\times3\times3$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{9}{16}$	$\frac{6}{16}$	$\frac{8}{16}\times5\times4$	$5\frac{1}{4}$	3	$3\frac{1}{2}$	800 and under 900
900 and under 1,000	8×3		$\frac{8}{16}\times4\frac{3}{4}\times3$	$\frac{7}{16}\times3\frac{1}{4}\times3$	$\frac{13}{16}$	$\frac{12}{16}$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{10}{16}$	$\frac{7}{16}$	$\frac{9}{16}\times5\times4\frac{1}{4}$	$5\frac{1}{2}$	3	$3\frac{1}{2}$	900 and under 1,000
1,000 and under 1,200	$8\frac{1}{2}\times3$		$\frac{9}{16}\times5\times3$	$\frac{8}{16}\times3\frac{1}{2}\times3$	$\frac{13}{16}$	$\frac{12}{16}$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{10}{16}$	$\frac{7}{16}$	$\frac{9}{16}\times5\times4\frac{1}{2}$	$5\frac{3}{4}$	3	4	1,000 and under 1,200
1,200 and under 1,500	9×3		$\frac{9}{16}\times5\times3\frac{1}{2}$	$\frac{8}{16}\times3\frac{1}{2}\times3$	$\frac{14}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{12}{16}$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{11}{16}$	$\frac{7}{16}$	$\frac{9}{16}\times5\frac{1}{2}\times4\frac{1}{2}$	6	$3\frac{1}{4}$	4	1,200 and under 1,500
1,500 and under 2,000	10×3		$\frac{10}{16}\times5\frac{1}{2}\times3\frac{1}{2}$	$\frac{9}{16}\times4\times3\frac{1}{2}$	$\frac{14}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{12}{16}$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{11}{16}$	$\frac{8}{16}$	$\frac{9}{16}\times6\times5$	$6\frac{1}{2}$	$3\frac{1}{2}$	4	1,500 and under 2,000
2,000 and under 2,500	12×3		$\frac{10}{16}\times6\times4$	$\frac{9}{16}\times4\frac{1}{2}\times3\frac{1}{2}$	$\frac{15}{16}$	$\frac{14}{16}$	$\frac{14}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{12}{16}$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{12}{16}$	$\frac{8}{16}$	$\frac{10}{16}\times6\frac{1}{2}\times5\frac{1}{2}$	$7\frac{1}{4}$	$3\frac{3}{4}$	4	2,000 and under 2,500
2,500 and under 3,000	$12\times3\frac{1}{4}$		$\frac{11}{16}\times6\frac{1}{4}\times4$	$\frac{10}{16}\times4\frac{1}{2}\times3\frac{1}{2}$	$\frac{15}{16}$	$\frac{14}{16}$	$\frac{14}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{12}{16}$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{12}{16}$	$\frac{8}{16}$	$\frac{10}{16}\times6\frac{1}{2}\times5\frac{1}{2}$	$7\frac{3}{4}$	4	4	2,500 and under 3,000
3,000 and under 3,500	$12\times3\frac{1}{2}$		$\frac{11}{16}\times6\frac{1}{2}\times4$	$\frac{10}{16}\times4\frac{1}{2}\times3\frac{1}{2}$	$\frac{16}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{14}{16}$	$\frac{14}{16}$	$\frac{13}{16}$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{12}{16}$	$\frac{9}{16}$	$\frac{10}{16}\times6\frac{1}{2}\times5\frac{1}{2}$	8	$4\frac{1}{2}$	4	3,000 and under 3,500

MEM.—The scantlings given in the above Table are intended for ships the length of which, measured from the fore part of the stem to the after part of the stern-post on the range of the upper deck, does not exceed seven times their extreme breadth or ten times their depth of hold, taken from the upper part of floors to the top of the upper deck beams. *For Ships which exceed in length, see Section* 16. *See also exceptions in Section* 9.

RIVETS. Diameter of Rivets required for Thickness of Plates	$\frac{5}{8}$ of an Inch.			$\frac{3}{4}$ of an Inch.			$\frac{7}{8}$ of an Inch.			1 Inch.			Rivets to be $\frac{1}{4}$ of an inch larger in diameter in the stem, stern-post, and keel.
	$\frac{5}{16}$	$\frac{6}{16}$	$\frac{7}{16}$	$\frac{8}{16}$	$\frac{9}{16}$	$\frac{10}{16}$	$\frac{11}{16}$	$\frac{12}{16}$	$\frac{13}{16}$	$\frac{14}{16}$	$\frac{15}{16}$	$\frac{16}{16}$	

* Hollow or flat keel plates and garboard strakes, and main sheerstrakes, are not to be less in breadth than as follows, *viz.*:—In ships under 500 tons, 2 ft.; in ships 500 and under 1,000 tons, 2 ft. 6 in; in ships 1,000 tons and upwards, 3 ft. When hollow or flat plate keels are adopted, their thickness should not be less than one and a half that of the garboard strake.—*For keels of other forms, see Section* 2.

‡ FLOOR PLATES.—The floor plates to be in depth at middle line according to the following rule, *viz.*:—To the vessel's depth, measured from the top of keel to the top of upper or spar deck beams amidships, add the extreme breadth of the vessel; two-fifths of that sum *in inches*, to be the depth of the floor plates at middle line; their thickness to be as given in Table; but at each end of the vessel, for one-quarter of her length, they may be reduced in thickness one-sixteenth of an inch where the plates are less than ten-sixteenths, and two-sixteenths of an inch where the plates are ten-sixteenths and upwards. The floor plates to extend up the bilges to a perpendicular height of twice the depth of floors amidships from upper side of keel at middle line, and not to be less moulded at their heads than the moulding of the frames. A floor plate to be fitted and rivetted to every frame; and at the ends of the vessel, the floor plates to be worked across the middle line, so as to unite the sides of the vessel efficiently to each other. Watercourses are to be formed through all the floor plates on each side of middle line, so as to allow water to reach the pumps freely.

† PLATING.—No plates to be less in length than five spaces of frames, except the fore and after hoods. No butts of outside plating in adjoining strakes to be nearer each other than two spaces of frames. In vessels under 1,200 tons the plating may be reduced from the thickness shewn in table, one-sixteenth of an inch forward and aft, for a distance not exceeding one-quarter of the length of the vessel from each end, below the upper edge of main sheerstrake, down to a perpendicular height from upper side of keel of three-fifths the internal depth of hold; and in ships of 1,200 tons and upwards, a reduction of two-sixteenths will be allowed; the plates next abaft and next afore the quarter length of the vessel, to be of an intermediate or graduated thickness, between that required amidships and the reduction allowed at the ends. In screw-propelled vessels, however, no reduction is to be made in the plating at the after end, below the lower part of the rudder trunk.

BUTT STRAPS.—All plates are to be well fitted, and secured to the frames and to each other; the butts to be closely fitted by planing or otherwise, and to be united by butt straps, of not less than the same thickness as the plates, and of sufficient breadth for rivetting, as described hereafter, and to be fitted with the fibre of the iron in the same direction as the fibre of the plates to which they are rivetted; the space between the plating and the frames to have solid filling or lining pieces, closely fitted in one length, and of the same breadth as the frames. It is recommended that in all cases the sheerstrake be an outside strake, so as to admit of the butt straps or lining pieces being extended, in one piece, from the foreside of the frame next afore the butts to the aftside of the frame next abaft the butts, or to admit of doubling the sheerstrake where it may be required.—*For breadth of sheerstrake see foot note above.*

‡ BEAMS.—Beam plates to be in depth one quarter of an inch for every foot in length of the midship beams, and to be in thickness one-sixteenth of an inch for every inch in depth of the said beams, and to be made of T bulb iron, or bulb plate, with double angle irons rivetted on upper edge; the two sides of each of these angle irons to be not less in breadth than three-fourths the depth of beam plate, and to be in thickness one-sixteenth of an inch for every inch of the two sides of the angle iron; where beams below the upper or middle deck (including orlop beams) have no deck laid upon them, the angle irons on their upper edges to be of the dimensions required for the angle iron of the reverse frames; or the beams may be composed of any other approved form of beam iron, equal to the strength herein required. All beams to be well and efficiently connected or rivetted to the corresponding frames, at the sides of the vessel, with bracket ends or knee-plates; each arm of knee plates at ends of beams not to be less in length than twice and a half the depth of beams, and to be in thickness equal to the beams The beams of each deck to be placed over each other, and pillared where practicable.

§ STRINGER AND TIE-PLATES.—All vessels to have stringer plates (of the thickness given in Table), upon the ends of each tier of beams. Those upon the ends of upper deck beams in vessels with two decks or tiers of beams, and on ends of middle deck beams in vessels with three decks or tiers of beams, to be in width one inch for every seven feet of the vessel's entire length, for half her length amidships, and from thence to the ends of the vessel they may be gradually reduced to three-fourths the width amidships—in no case, however, is the width to be less than eighteen inches amidships. The stringer plates are to be fitted home and rivetted to the outside plating at all upper decks, and at the middle deck in vessels having three decks, with angle iron of the dimensions given in Table: the middle deck stringer plate to have an additional angle iron extending all fore and aft inside of the frames, rivetted to the reverse angle iron on the frames, and to the stringer plate. Stringer plates on ends of beams below the upper deck in vessels with two decks, or below middle deck in vessels with three decks, may be reduced in width to three-fourths the midship breadth above named, this breadth is to be extended all fore and aft and to have an angle iron of the dimensions given in Table, extending all fore and aft, rivetted to the reverse angle iron on the frames, and to the stringer plates. In cases where no deck is laid, and the width of stringer plate on ends of hold beams is objected to, it may be reduced, provided such reduction be fully compensated for. The objectionable practice of cutting through the stringer plates for the admission of wood roughtree stanchions will not be allowed. All vessels are to have tie-plates ranging all fore and aft upon each tier of beams on each side of hatchways, and wherever practicable from side to side diagonally, to be in width one and a half the depth of beams, and of the thickness required for stringer plates. The said plates are to be well rivetted to each other, and to beams, deck hooks, and transoms; and all butts to be properly shifted. Upon hold beams where no deck is to be laid, or where tie-plates would interfere with the stowage of cargo, an angle iron of the dimensions given in Table for angle iron on beam stringers, placed at middle line, extending fore and aft where practicable, and well rivetted to all beams, deck hooks, and transoms, will be admitted in lieu thereof.

‖ RIVETS AND RIVETTING.—The rivets to be of the best quality, and to be in diameter as per Table; the rivet holes to be regularly and equally spaced and carefully punched opposite each other from the faying surfaces, in the laps and lining pieces or butt straps; and to be countersunk all through the outer plating; the rivets not to be nearer to the butts, or edges of the plating, lining pieces to butts, or of any angle iron, than a space not less than their own diameter, and not to be further apart from each other than four times their diameter, or nearer than three times their diameter, and to be spaced through the frames and outside plating, and in reversed angle iron, a distance equal to eight times their diameter apart. When rivetted up they are completely to fill the holes, and their points or outer ends are to be round or convex, and not to be below the surface of the plating through which they are rivetted. All vessels to have all edges or horizontal joints of outside plating double rivetted from the keel to the height of upper part of bilges, all fore and aft; but vessels of 700 *tons and above*, intended for the highest grade, are to have all edges or horizontal joints of outside plating double rivetted *throughout*. The stem, stern-post, keel, edges of garboard strakes and sheerstrakes, and butts of outside plating, and butts of floor plates, breasthooks, transoms, and plates of beams, also butts of keelsons, stringers, shelf plates, and all longitudinal ties, to be double rivetted in all vessels. The overlap of plating, where double rivetting is required, not to be less than five and a half times the diameter of the rivets; and where single rivetting is admitted, to be not less in breadth than three and a quarter times the diameter of the rivets. If double rivetting be adopted where single rivetting is allowed by the Rules, the diameter of the rivets may be reduced one-sixteenth of an inch below that prescribed by the Rules, provided that in no case the diameter be less than five-eighths of an inch. The butts and edges of outside plating to be truly fitted, carefully caulked, and made water-tight.

Lloyd's Register of Shipping, London, 18th June, 1863.

To illustrate Mr. Fairbairn's Paper on Iron-Plated Ships.

Fig. 1.

Transverse Section

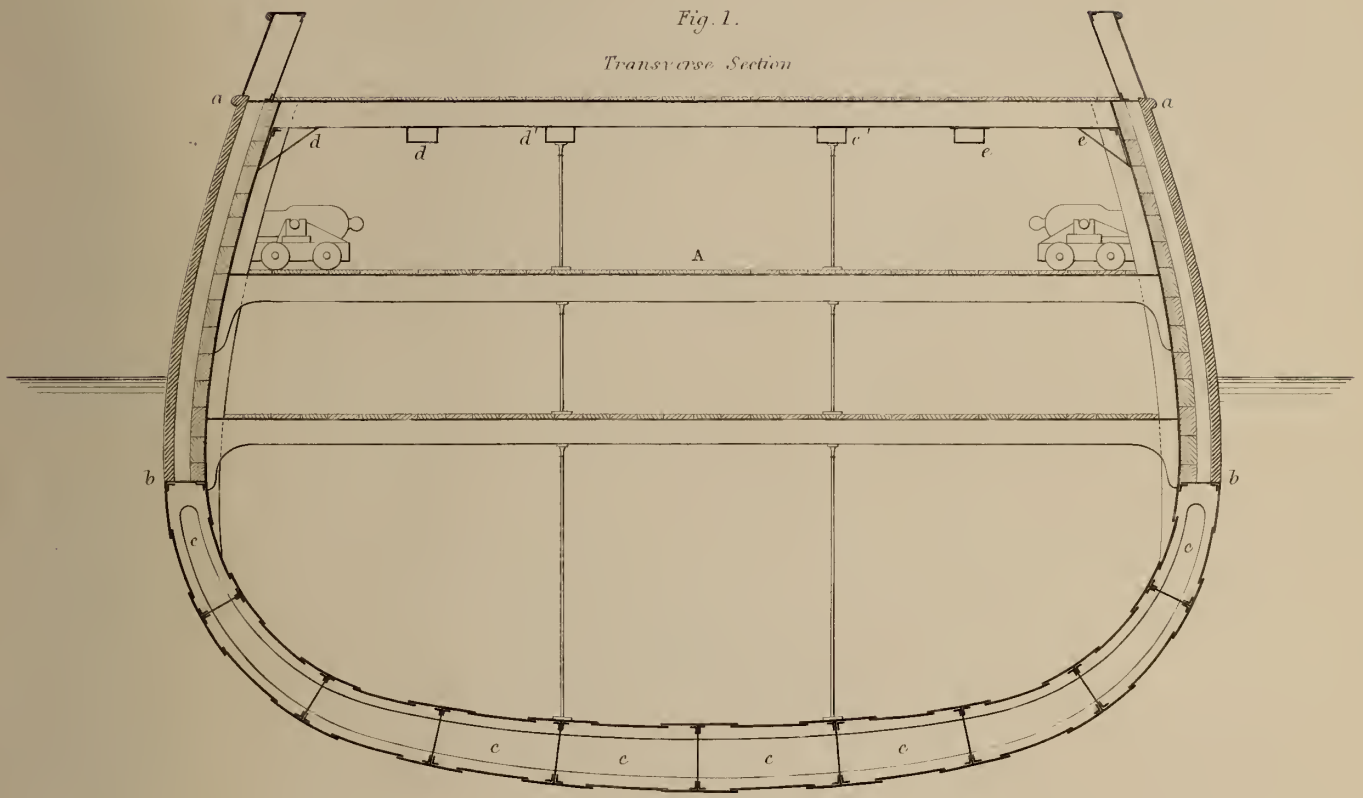


Fig. 2.

Section shewing the connection of the upper deck beam with the longitudinal cellular stringer.

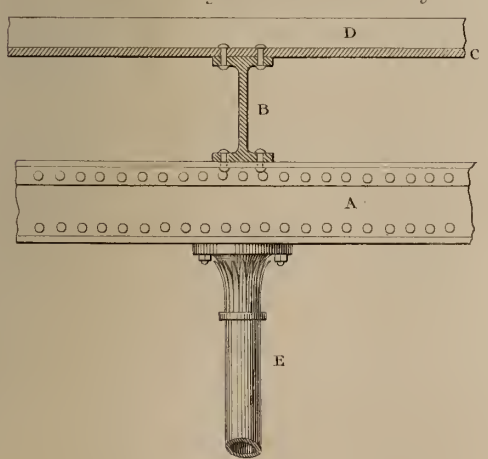
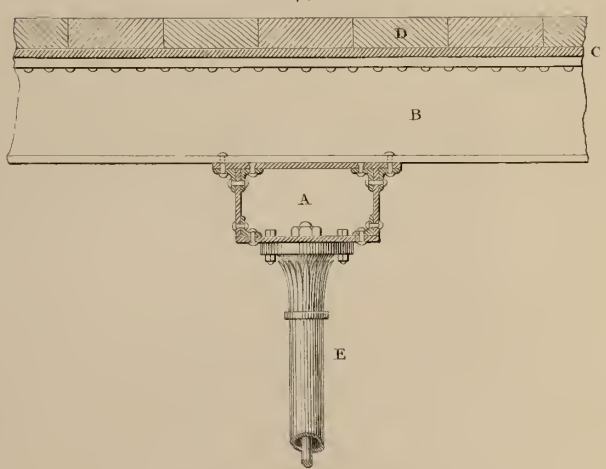


Fig. 3.

Section of the longitudinal cell, the deck beam, &c. of the upper deck.



To illustrate Mr. Barnaby's Paper on the Steering of Ships.

Fig. 1.

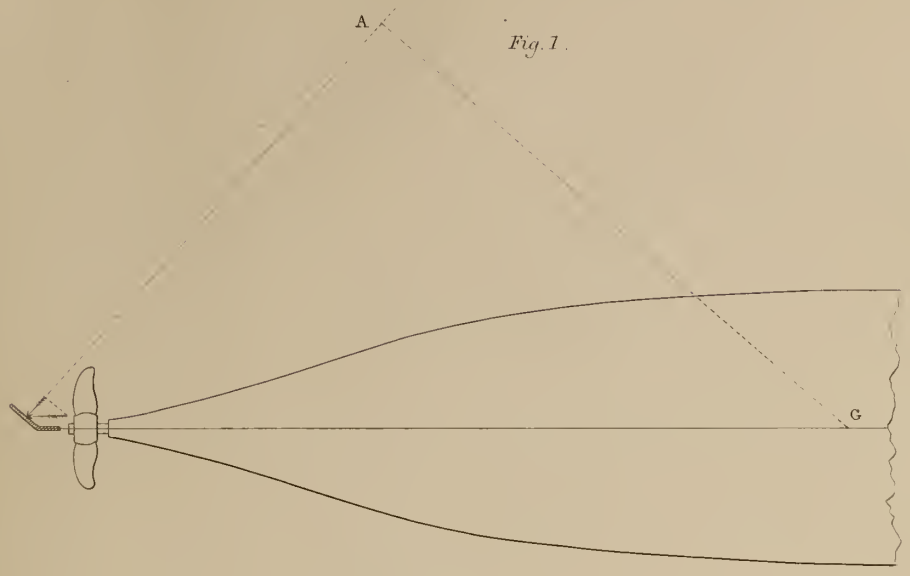


Fig. 2.

Balanced Rudder with stern post removed.

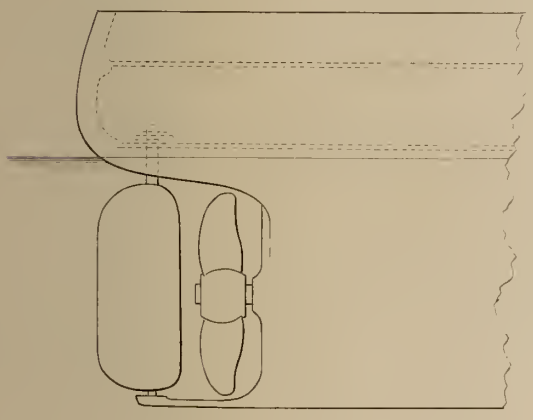


Fig. 3.

Balanced Rudder with two screws.

Profile

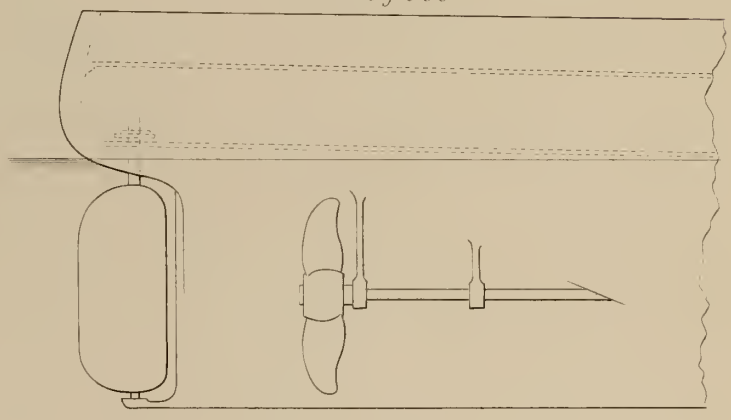


Fig. 5

Steering screw in the bow.

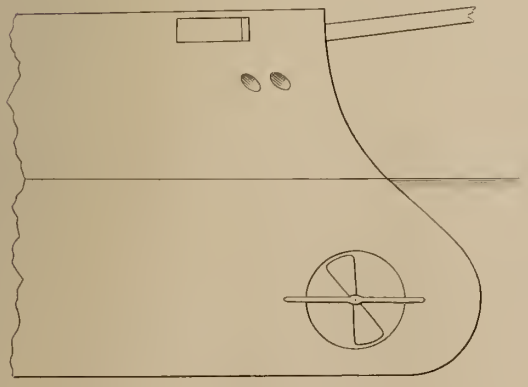
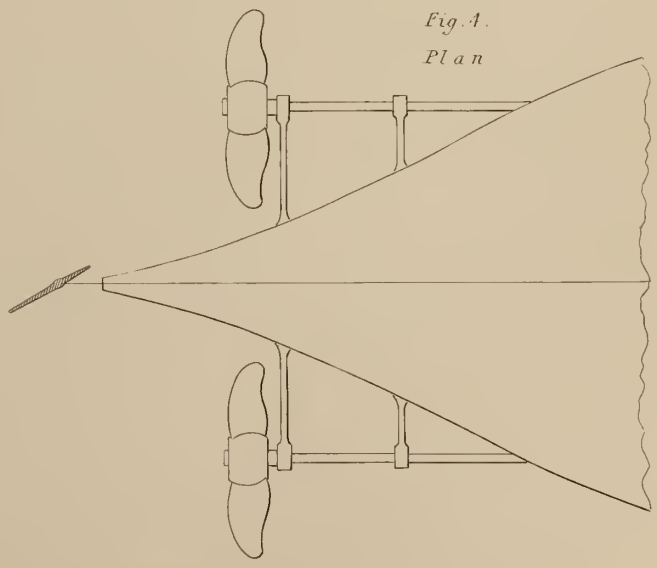


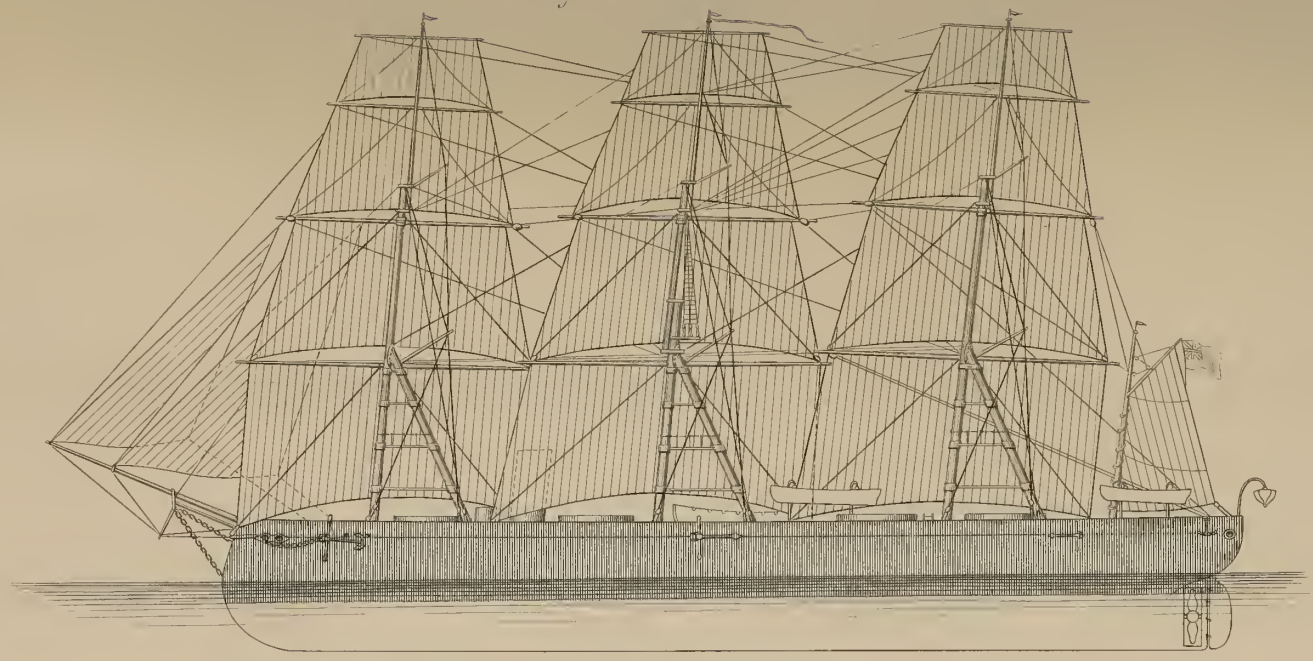
Fig. 4.

Plan



To illustrate Captn Coles's Paper on Sea-going Shield Ships.

Fig. 1



Shield Ship under plain sail spreading 32,456 square feet of canvass.

Fig. 2

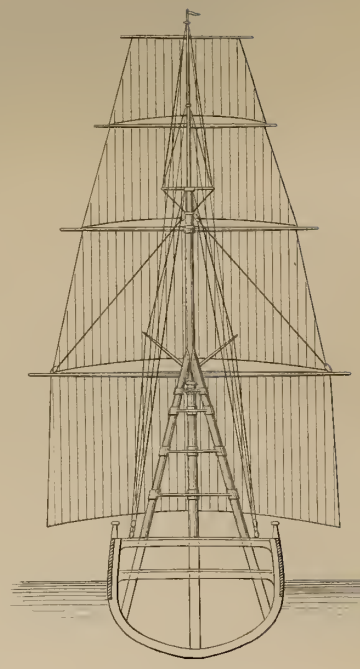
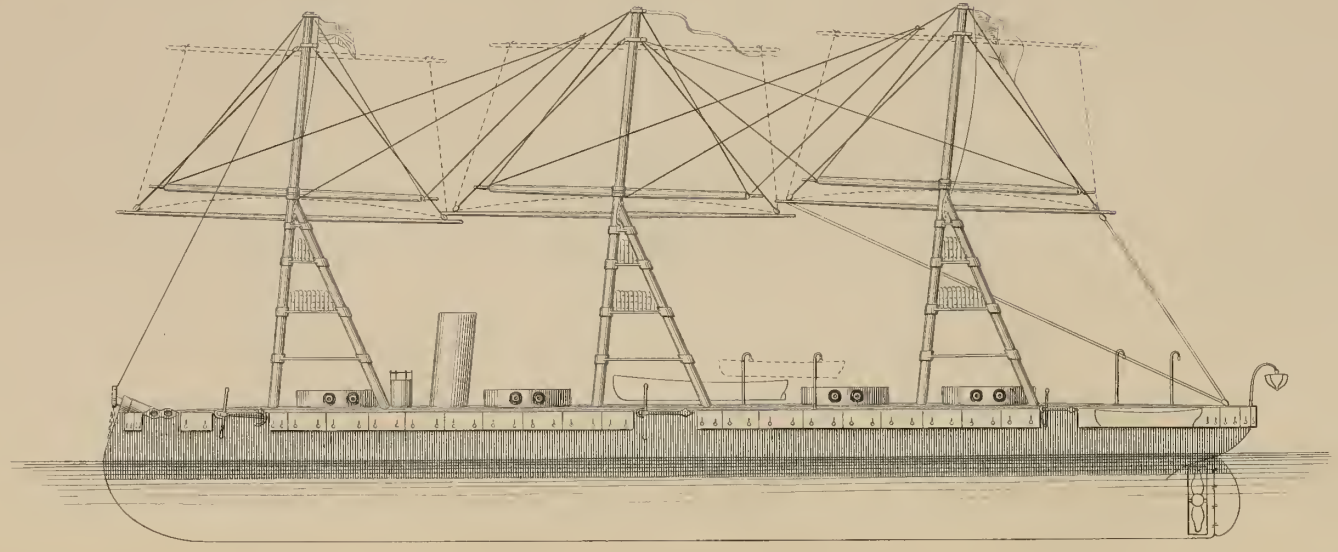
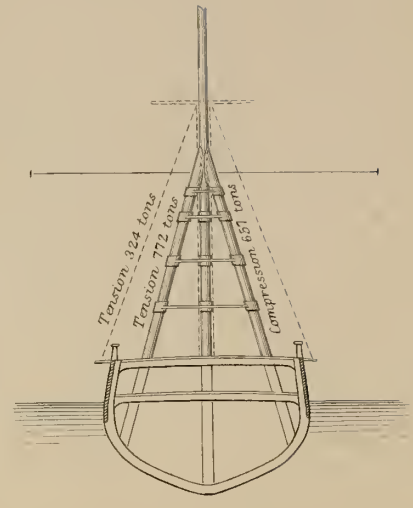


Fig. 3



Shield Ship prepared for action.

Fig. 4

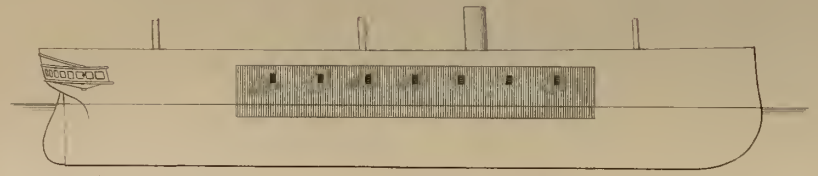


J W. Lowry, sculpt

To illustrate Captn Coles's Paper on Sea-going Shield Ships.

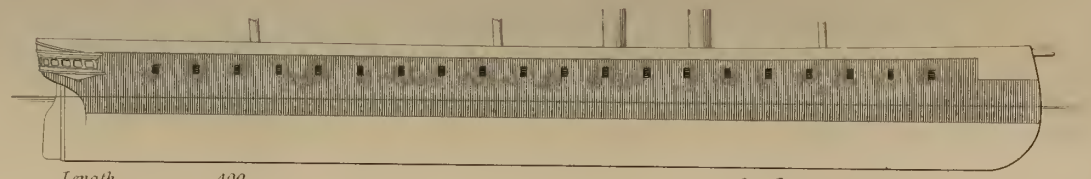
The shading represents the armour plating and the figures its thickness in inches

DEFENCE *class* (4½)



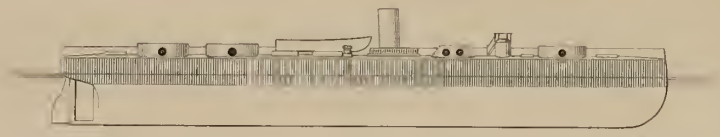
Length	280	Speed	11. 3
Beam	54. 2	Men	455
Tonnage	3720	Guns 5.68 Prs & 2. 110 Prs	
Draught of Water	25. 6	Weight of Broadside 560 lbs.	

MINOTAUR *class* (5½)



Length	400	Speed	14. 3
Beam	59. 3	Men	704
Tonnage	6621	Guns 13. 68 Prs & 4. 110 Prs	
Draught of Water	26. 2	Weight of Broadside 1324 lbs.	

PRINCE ALBERT. (4½)

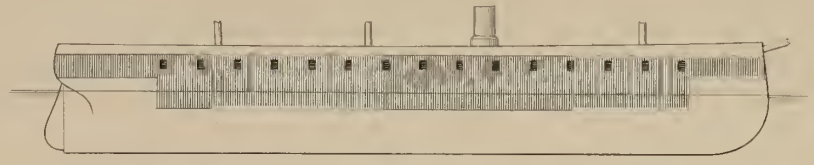


Length	240	Speed	11. 4
Beam	48	Men	160
Tonnage	2529	Guns 3. 300 Prs & 2. 100 Prs	
Draught of Water	20	Weight of Broadside 1120 lbs	

ROYAL OAK *class* (4½)

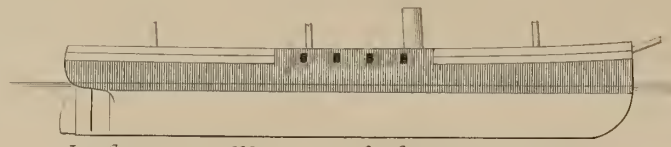
Length	273	Speed	11. 5
Beam	58. 5	Men	600
Tonnage	4045	Guns 12. 68 Prs & 4. 110 Prs	
Draught of Water	26. 7	Weight of Broadside 1256 lbs.	

VALIANT *class* (4½)



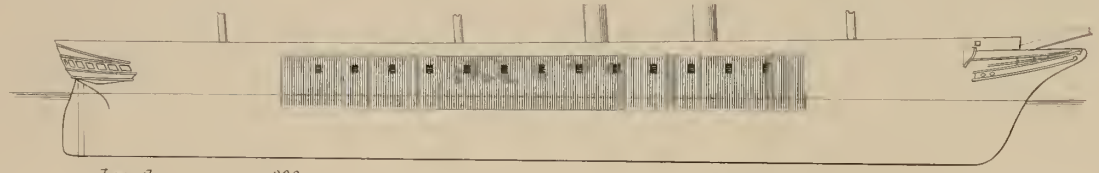
Length	280	Speed	11. 75
Beam	56. 3	Men	600
Tonnage	4063	Guns 12. 68 Prs & 3. 100 Prs	
Draught of Water	25. 2	Weight of Broadside 1146 lbs	

FAVORITE. (4½)



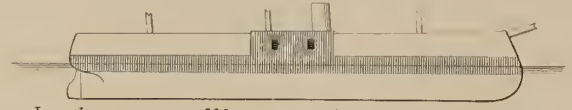
Length	225	Speed	10. 8
Beam	46. 9	Men	160
Tonnage	2186	Guns 2. 68 Prs & 2. 110 Prs	
Draught of Water	21. 11	Weight of Broadside 356 lbs.	

WARRIOR. (4½)



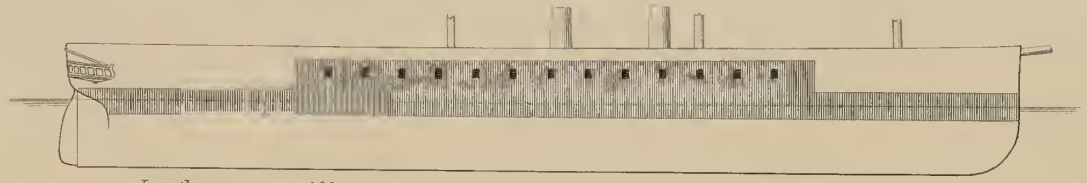
Length	380	Speed	14. 3
Beam	58	Men	709
Tonnage	6109	Guns 13. 68 Prs	
Draught of Water	26. 2	Weight of Broadside 884 lbs.	

ENTERPRISE. (4½)



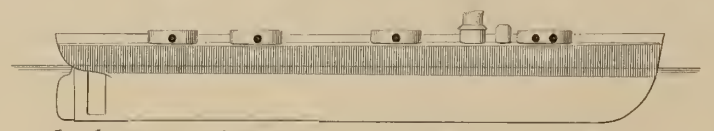
Length	180	Speed	9. 5
Beam	36	Men	80
Tonnage	990	Guns 2. 110 Prs	
Draught of Water	15. 6	Weight of Broadside 136 lbs.	

ACHILLES. (4½)



Length	380	Speed	14. 1
Beam	58. 3	Men	704
Tonnage	6079	Guns 13. 68 Prs	
Draught of Water	26. 2	Weight of Broadside 884 lbs.	

ROYAL SOVEREIGN. (5½)

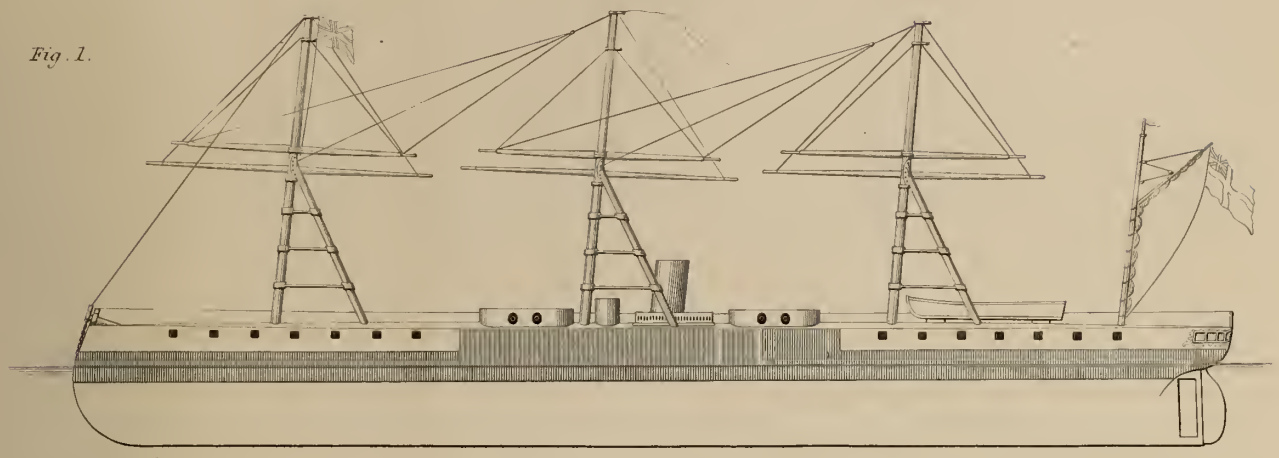


Length	240	Speed	12. 2
Beam	62	Men	200
Tonnage	3963	Guns 5. 300 Prs	
Draught of Water	28. 6	Weight of Broadside 1500 lbs.	

To illustrate Capt.n Coles's Paper on Sea-going Shield Ships.

PROPOSED SHIELD SHIP.

Fig. 1.

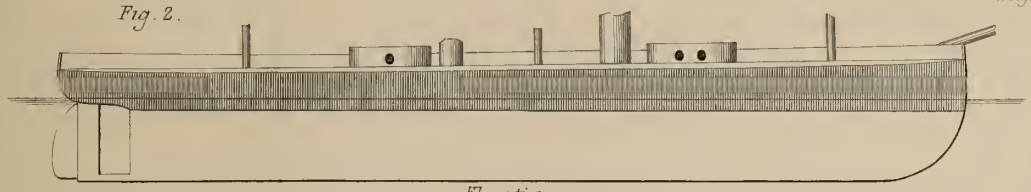


Length	285 Ft
Beam	52
Tonnage	3700
Draught of Water	24

Speed	13 knots
Men	200
Guns	4 . 300 Prs
Weight of Broadside	1200 lbs

NAUGHTY CHILD.

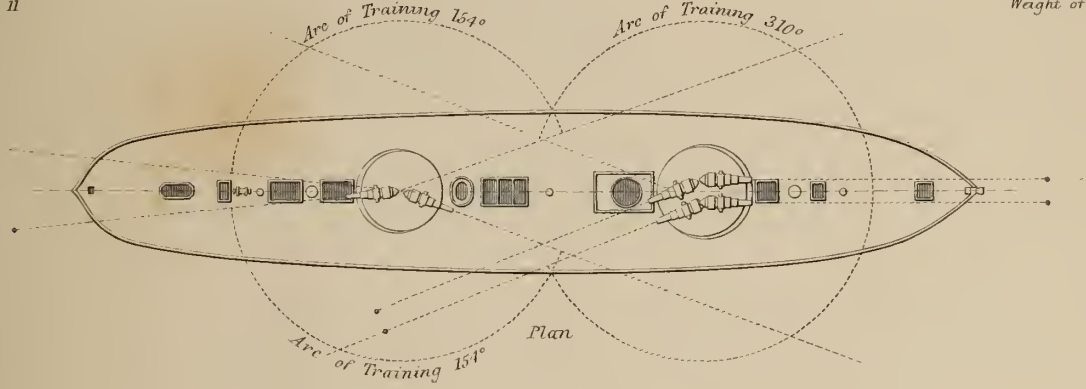
Fig. 2.



Elevation

Length	225
Beam	46 . 9
Tonnage	2186
Draught of Water	21 11

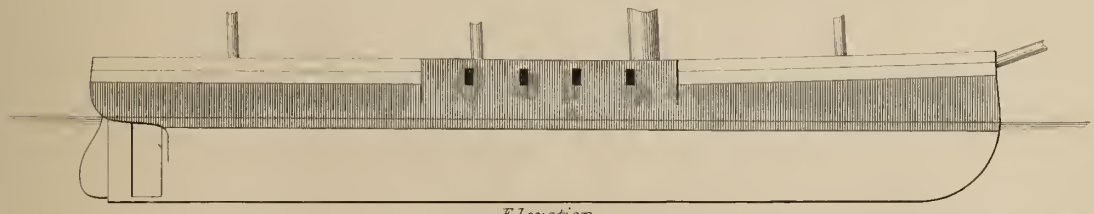
Speed	10 . 8
Men	120
Guns	3 . 300 Prs
Weight of Broadside	900 lbs.



Plan

FAVORITE.

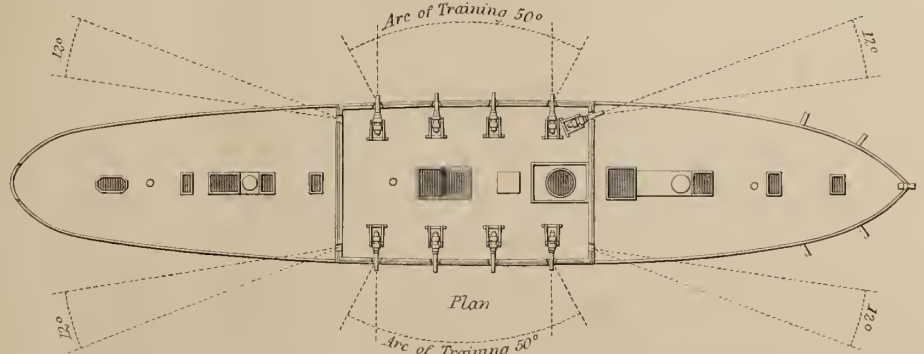
Fig. 3.



Elevation

Length	225
Beam	46 9
Tonnage	2186
Draught of Water	21 11

Speed	10 8
Men	160
Guns	2 . 68 Prs & 2 . 110 Prs
Weight of Broadside	356 lbs.



Plan

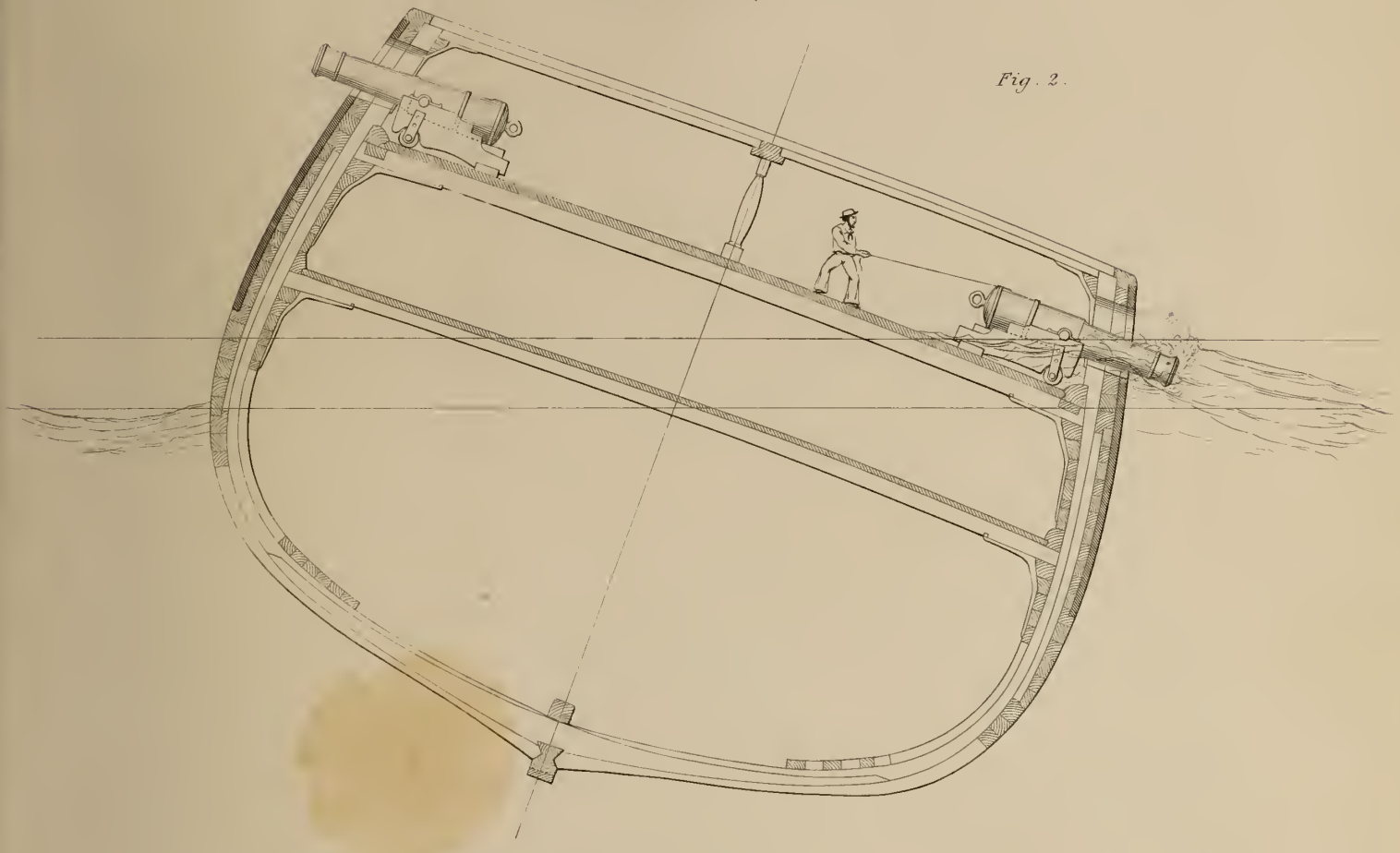
J. W. Lowry sculp.t

To illustrate Capt.n Coles's Paper on Sea-going Shield Ships.

FAVORITE

Inclined at an angle of 20°

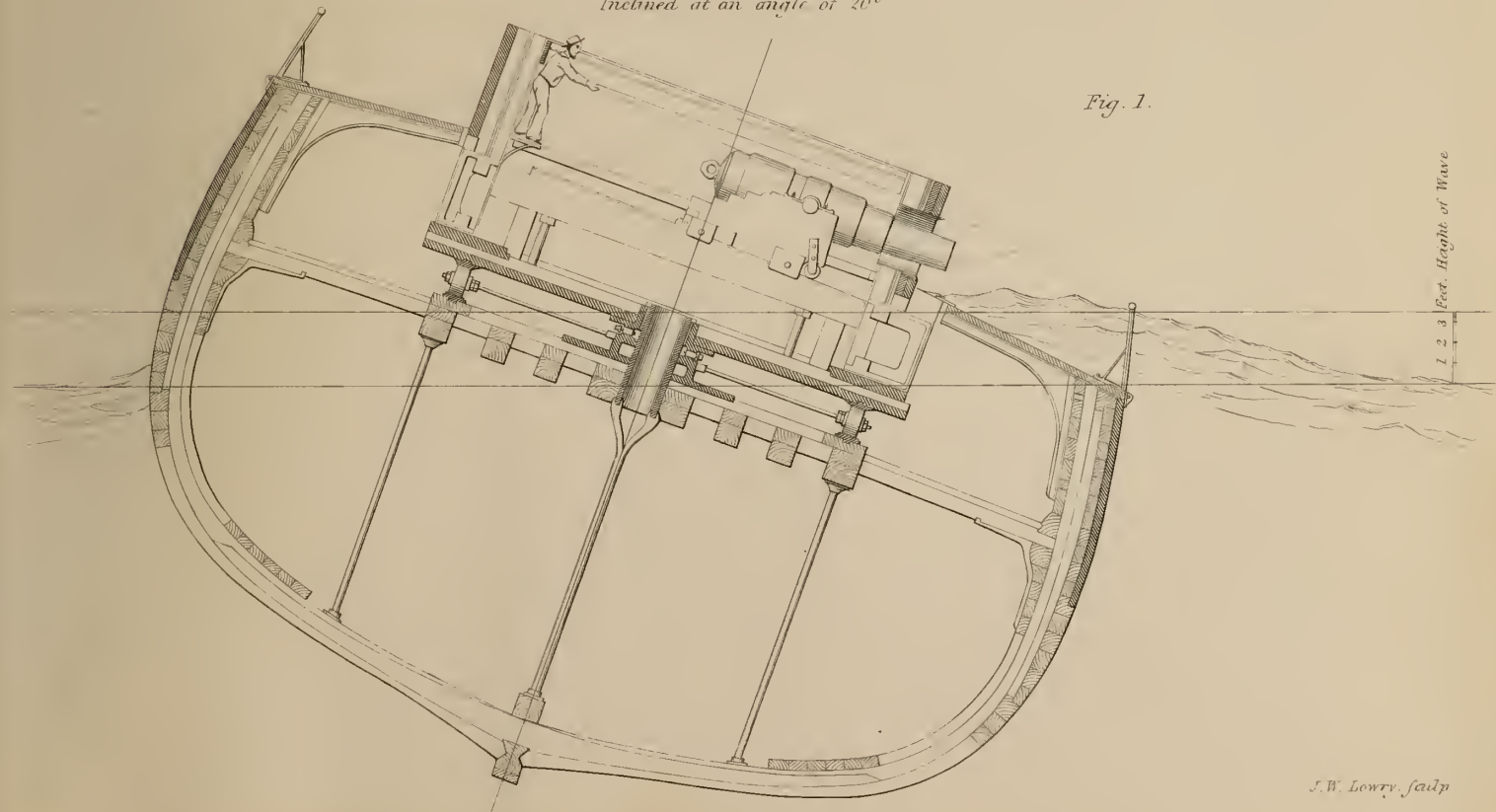
Fig. 2.



NAUGHTY CHILD.

Inclined at an angle of 20°

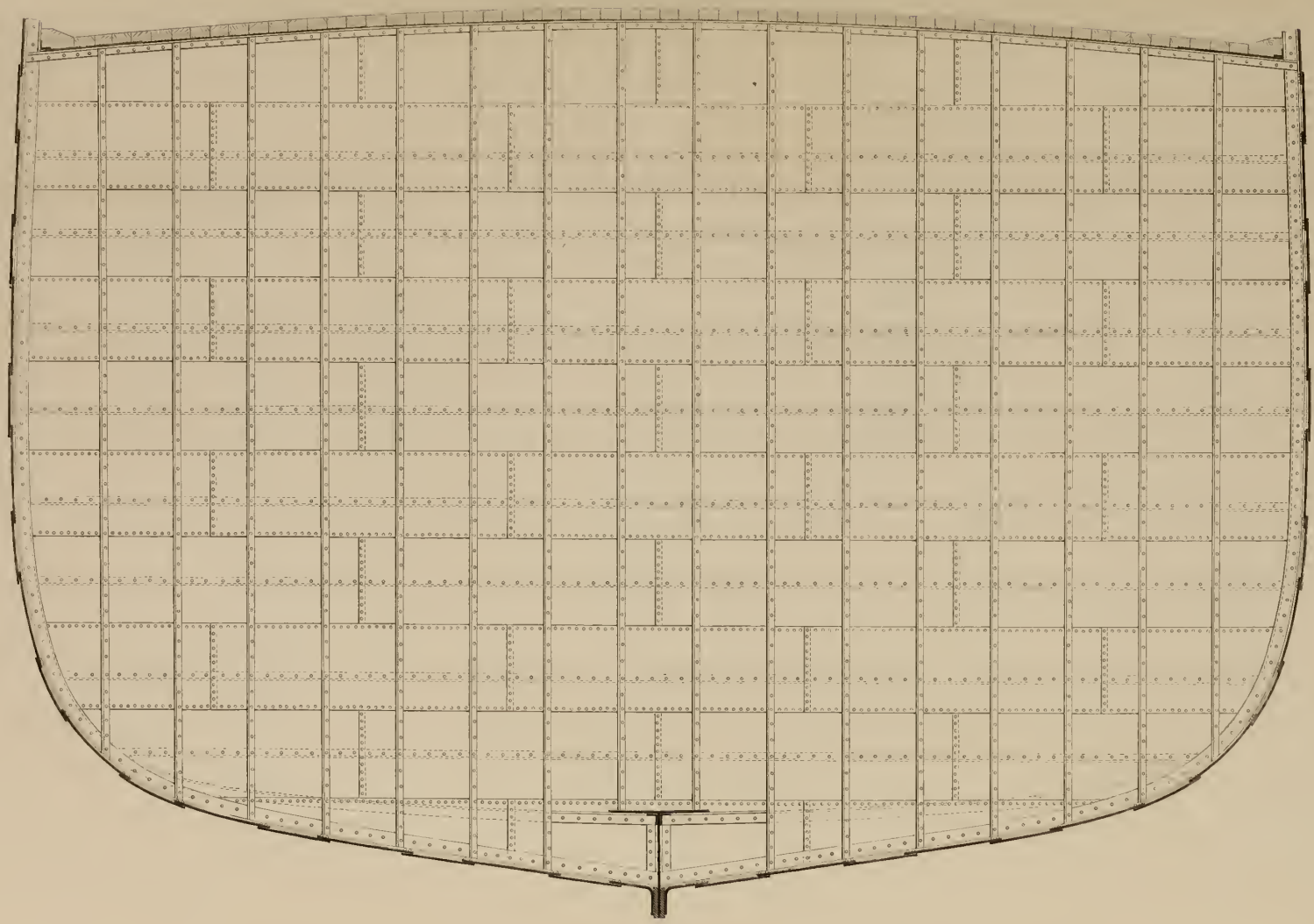
Fig. 1.

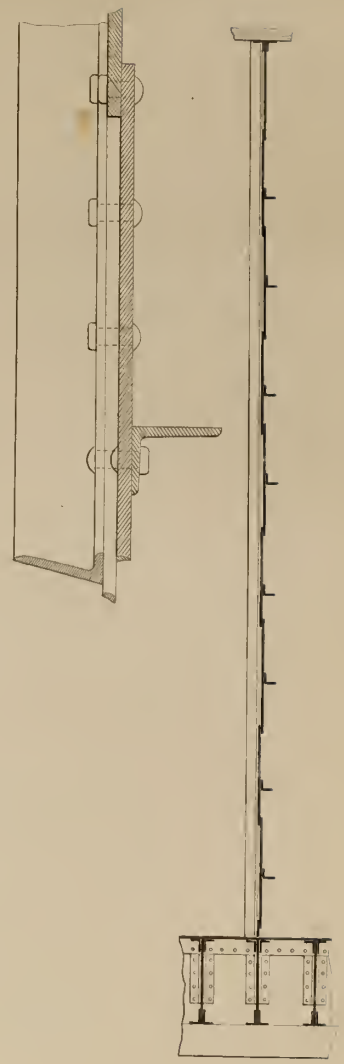


J.W. Lowry. sculp

To illustrate Mr. Mackrow's Paper on Iron Bulkheads

Bulkhead of Parramatta

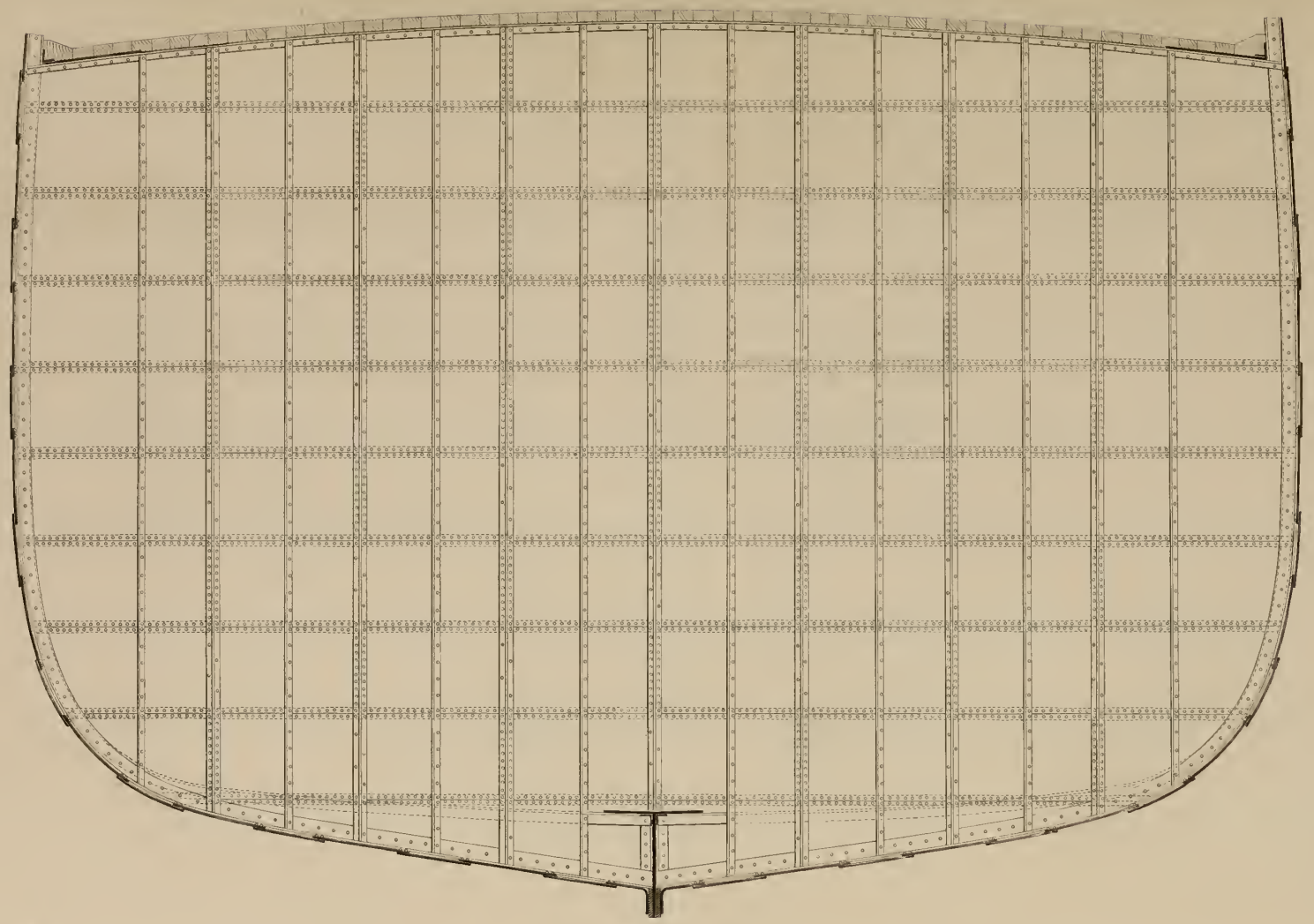


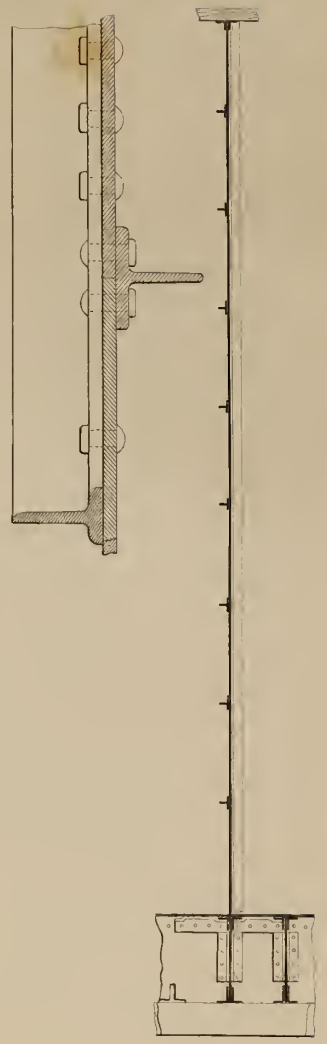


J.W. Lowry fc

To illustrate Mr. Mackrow's Paper on Iron Bulkheads.

Proposed Bulkhead.





J. W. Lowry, fc.

To illustrate Mr. Gladstone's Paper on the Hydro-testometer.

Fig. 1.

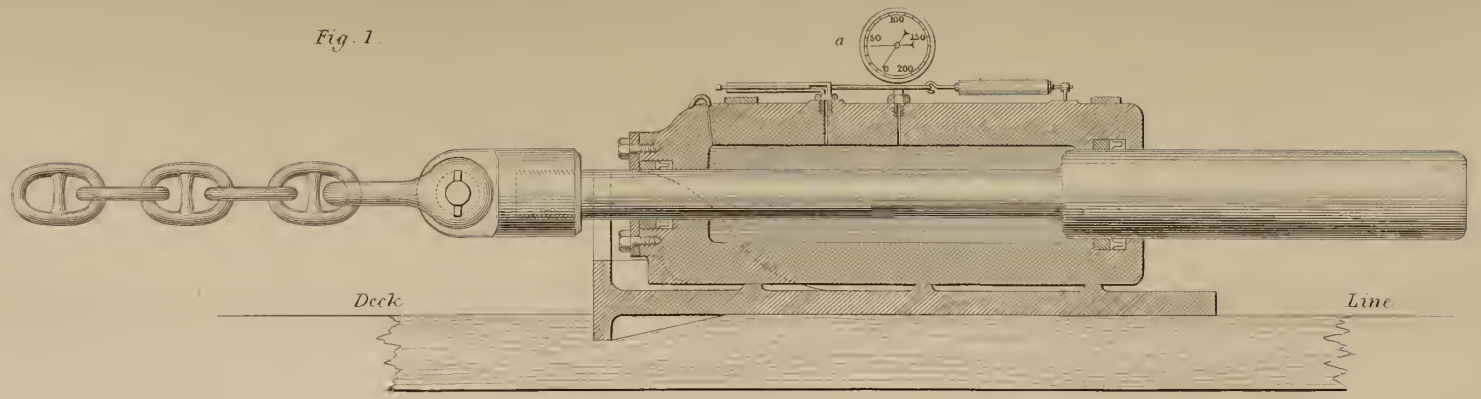
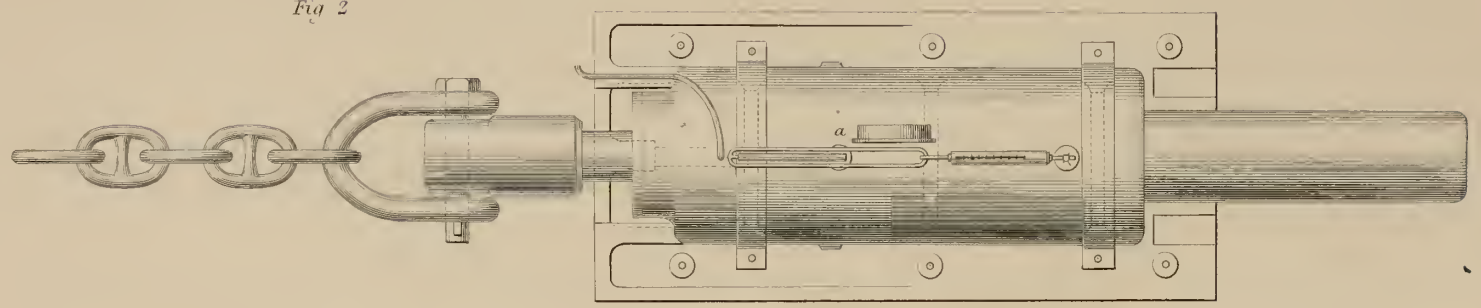
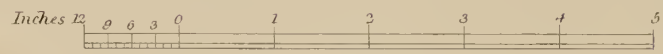


Fig 2





J. W. Lowry sculpt.

Fig. 3.

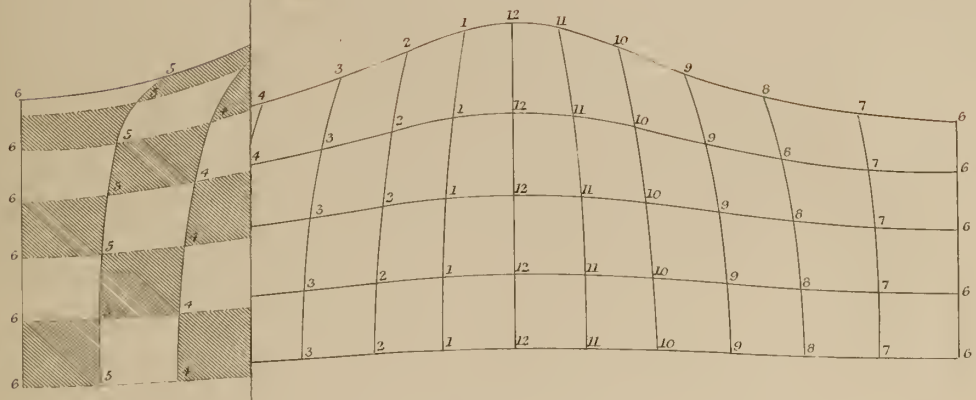


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Fig. 6.

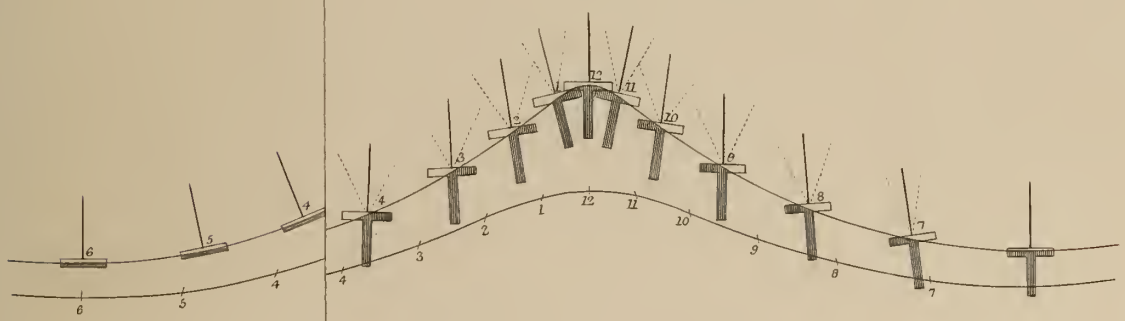
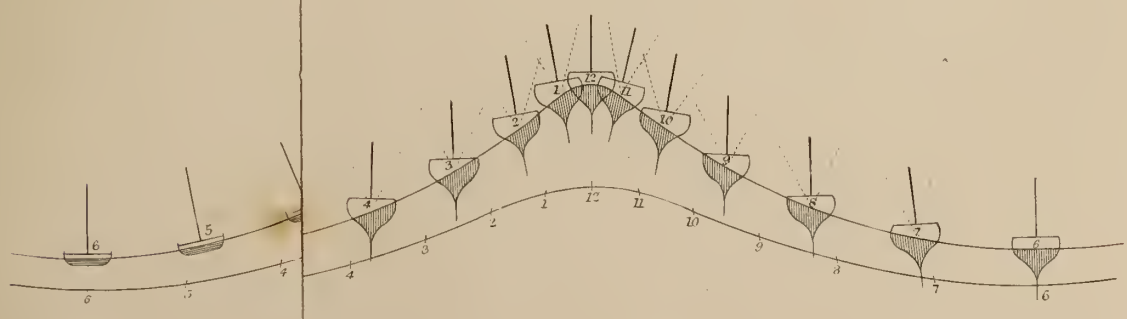


Fig. 9.



J Quant del^{t}

J.W. Lowry fculp^{t}

To illustrate Mr Scott Russell's Paper on Rolling.

Fig. 1.

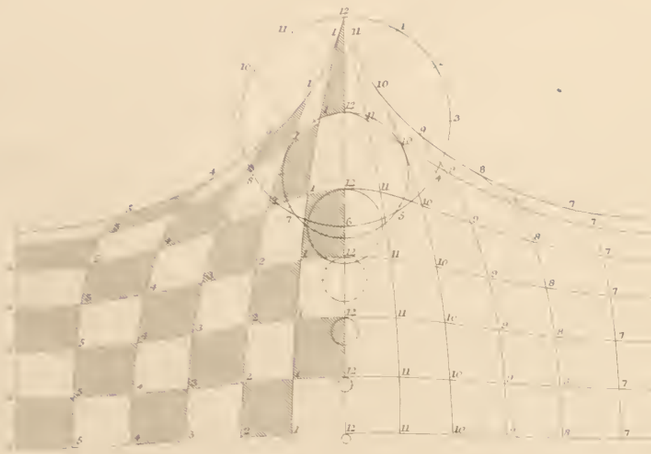


Fig. 2.

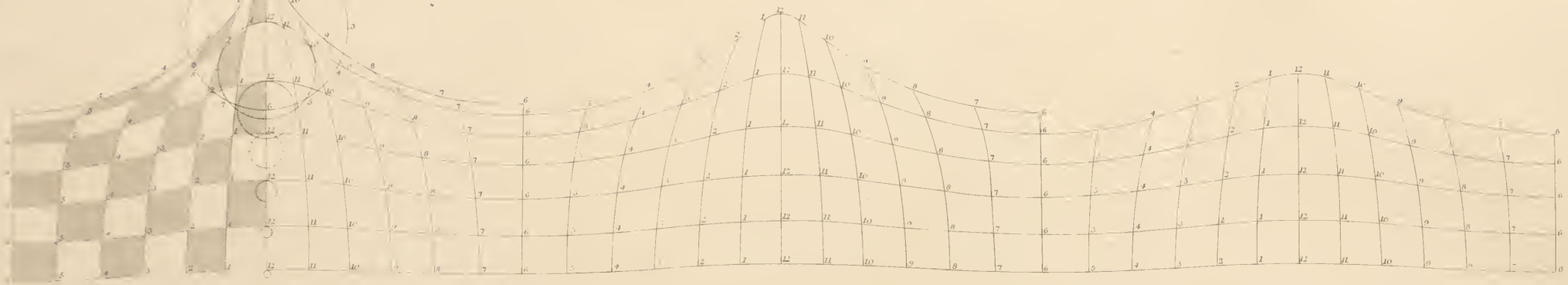


Fig. 3

Fig. 10

Fig. 11.

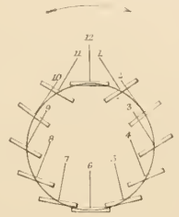


Fig. 4.

Fig. 5.

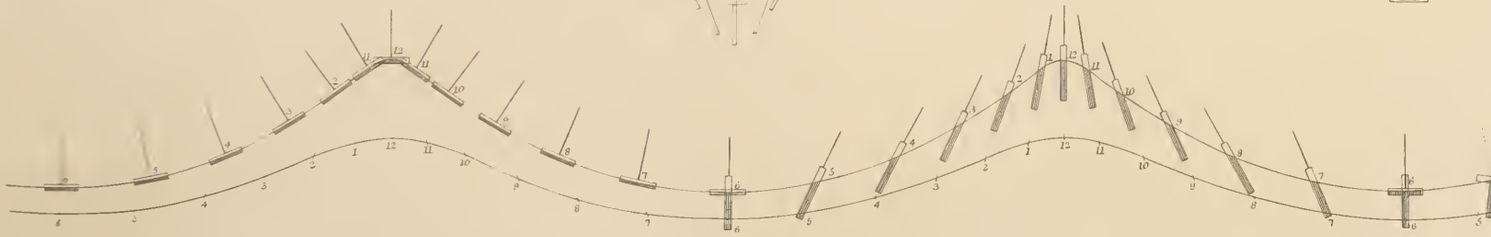


Fig. 6.

Fig. 7.

Fig. 8.

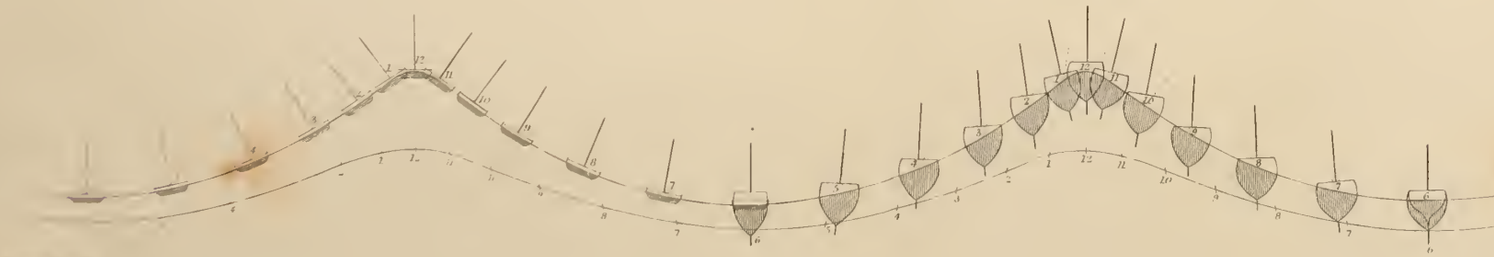


Fig. 9.

A W Lowry, Sculpt

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